

Doc. 21 - 115 -

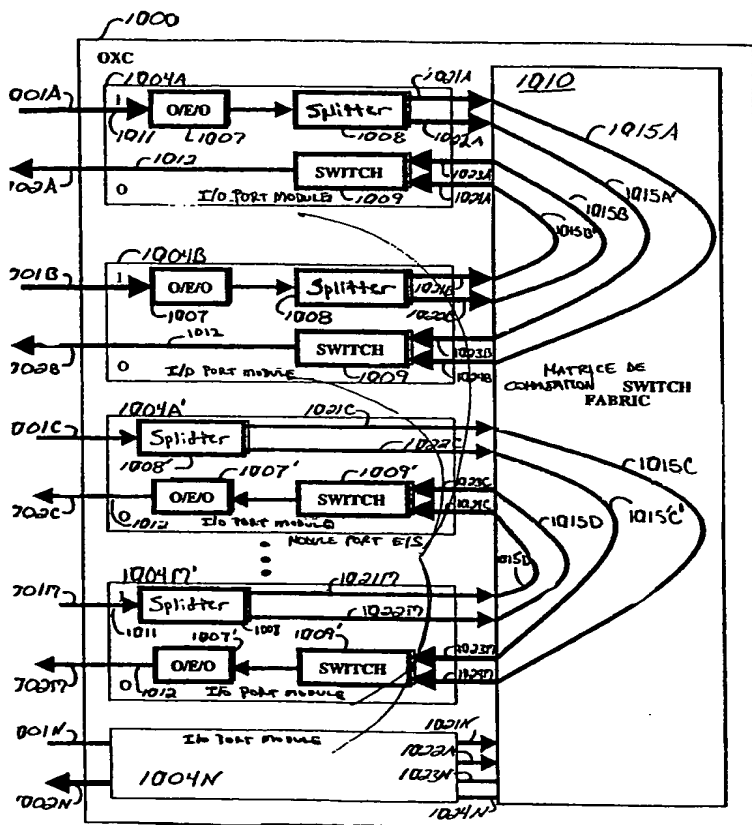


**(10) International Publication Number**  
**WO 01/33897 A2**

## PCT

- |  |                               |                              |    |            |                               |    |            |                               |    |            |                               |    |            |                               |    |            |                           |    |            |                            |    |            |                              |    |  |
|--|-------------------------------|------------------------------|----|------------|-------------------------------|----|------------|-------------------------------|----|------------|-------------------------------|----|------------|-------------------------------|----|------------|---------------------------|----|------------|----------------------------|----|------------|------------------------------|----|--|
| <p><b>(51) International Patent Classification?:</b> H04Q 11/00</p> <p><b>(21) International Application Number:</b> PCT/US00/30494</p> <p><b>(22) International Filing Date:</b><br/>2 November 2000 (02.11.2000)</p> <p><b>(25) Filing Language:</b> English</p> <p><b>(26) Publication Language:</b> English</p> <p><b>(30) Priority Data:</b></p> <table border="0"> <tr> <td>60/162,936</td> <td>2 November 1999 (02.11.1999)</td> <td>US</td> </tr> <tr> <td>60/170,094</td> <td>10 December 1999 (10.12.1999)</td> <td>US</td> </tr> <tr> <td>60/170,095</td> <td>10 December 1999 (10.12.1999)</td> <td>US</td> </tr> <tr> <td>60/170,093</td> <td>10 December 1999 (10.12.1999)</td> <td>US</td> </tr> <tr> <td>60/170,092</td> <td>10 December 1999 (10.12.1999)</td> <td>US</td> </tr> <tr> <td>60/186,108</td> <td>1 March 2000 (01.03.2000)</td> <td>US</td> </tr> <tr> <td>60/200,425</td> <td>28 April 2000 (28.04.2000)</td> <td>US</td> </tr> <tr> <td>09/704,444</td> <td>1 November 2000 (01.11.2000)</td> <td>US</td> </tr> </table> | 60/162,936                    | 2 November 1999 (02.11.1999) | US | 60/170,094 | 10 December 1999 (10.12.1999) | US | 60/170,095 | 10 December 1999 (10.12.1999) | US | 60/170,093 | 10 December 1999 (10.12.1999) | US | 60/170,092 | 10 December 1999 (10.12.1999) | US | 60/186,108 | 1 March 2000 (01.03.2000) | US | 60/200,425 | 28 April 2000 (28.04.2000) | US | 09/704,444 | 1 November 2000 (01.11.2000) | US | <p><b>(71) Applicant:</b> XROS, INC. [US/US]; 2305 Mission College Boulevard, Santa Clara, CA 95054 (US).</p> <p><b>(72) Inventors:</b> RAMASWAMI, Rajiv; 758 Carlisle Way, Sunnyvale, CA 94087 (US). CLARK, Steven; 922 Matadero Avenue, Palo Alto, CA 94306 (US). WARD, Robert, R.; 803 Selkirk Place, Sunnyvale, CA 94087 (US).</p> <p><b>(74) Agents:</b> SCHAAAL, William, W. et al.; Blakely, Sokoloff, Taylor &amp; Zafman, 7th floor, 12400 Wilshire Blvd., Los Angeles, CA 90025-1026 (US).</p> <p><b>(81) Designated States (<i>national</i>):</b> AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW.</p> |
| 60/162,936   | 2 November 1999 (02.11.1999)  | US                           |    |            |                               |    |            |                               |    |            |                               |    |            |                               |    |            |                           |    |            |                            |    |            |                              |    |  |
| 60/170,094   | 10 December 1999 (10.12.1999) | US                           |    |            |                               |    |            |                               |    |            |                               |    |            |                               |    |            |                           |    |            |                            |    |            |                              |    |  |
| 60/170,095   | 10 December 1999 (10.12.1999) | US                           |    |            |                               |    |            |                               |    |            |                               |    |            |                               |    |            |                           |    |            |                            |    |            |                              |    |  |
| 60/170,093   | 10 December 1999 (10.12.1999) | US                           |    |            |                               |    |            |                               |    |            |                               |    |            |                               |    |            |                           |    |            |                            |    |            |                              |    |  |
| 60/170,092   | 10 December 1999 (10.12.1999) | US                           |    |            |                               |    |            |                               |    |            |                               |    |            |                               |    |            |                           |    |            |                            |    |            |                              |    |  |
| 60/186,108   | 1 March 2000 (01.03.2000)     | US                           |    |            |                               |    |            |                               |    |            |                               |    |            |                               |    |            |                           |    |            |                            |    |            |                              |    |  |
| 60/200,425   | 28 April 2000 (28.04.2000)    | US                           |    |            |                               |    |            |                               |    |            |                               |    |            |                               |    |            |                           |    |            |                            |    |            |                              |    |  |
| 09/704,444   | 1 November 2000 (01.11.2000)  | US                           |    |            |                               |    |            |                               |    |            |                               |    |            |                               |    |            |                           |    |            |                            |    |            |                              |    |  |

*[Continued on next page]*



**(57) Abstract:** In one embodiment, a scalable cross-connect switching system and its corresponding method perform a bridging operation by splitting the incoming light signal into at least a first bridged light signal and a second bridged light signal. The first bridged light signal has a power level equal to or substantially greater than a power level of the second bridged light signal. The disproportionate power levels provide low-loss bridging. Light signals based on these bridged light signals are routed through multiple switch fabrics which provide redundancy in case of failure by switching within the switch fabric. To detect failures, a test access port is configured for monitoring multiple optical paths.

**WO 01/33897 A2**



(84) **Designated States (regional):** ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

**Published:**

— *Without international search report and to be republished upon receipt of that report.*

*For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

AN OPTICAL CROSS-CONNECT SWITCHING SYSTEM WITH BRIDGING,  
TEST ACCESS AND REDUNDANCY

CROSS REFERENCE TO RELATED APPLICATIONS

- 5           This non-provisional U.S. Patent Application claims the benefit of U.S. Provisional Patent Application No. 60/162,936 entitled "OPTICAL CROSSCONNECT WITH OPTICAL TO ELECTRICAL CONVERTERS" filed on November 2, 1999 by inventor Rajiv Ramaswami; and also claims the benefit of U.S. Provisional Patent Application No. 60/170,094 entitled "OPTICAL
- 10   CROSSCONNECT WITH BRIDGING, TEST ACCESS AND REDUNDANCY" filed on December 10, 1999 by inventors Rajiv Ramaswami and Robert R. Ward; and also claims the benefit of U.S. Provisional Patent Application No. 60/170,095 entitled "OPTICAL CROSSCONNECT WITH LOW-LOSS BRIDGING, TEST ACCESS AND REDUNDANCY" filed on December 10, 1999 by inventors
- 15   Steven Clark and Rajiv Ramaswami; and also claims the benefit of U.S. Provisional Patent Application No. 60/170,093 entitled "1+1 OPTICAL PROTECTION USING OPTICAL CROSSCONNECT" filed on December 10, 1999 by inventors Rajiv Ramaswami and Robert R. Ward; and also claims the benefit of U.S. Provisional Patent Application No. 60/170,092 entitled
- 20   "SIGNALING INTERFACE BETWEEN OPTICAL CROSSCONNECT AND ATTACHED EQUIPMENT" filed on December 10, 1999 by inventor Rajiv Ramaswami; and also claims the benefit of U.S. Provisional Patent Application No. 60/186,108 entitled "1:N PROTECTION BETWEEN CLIENTS AND ALL-OPTICAL CROSSCONNECTS" filed on March 1, 2000 by inventors Kent
- 25   Erickson, Subhashini Kaligotla, and Rajiv Ramaswami; and also claims the benefit of U.S. Provisional Patent Application No. 60/200,425 entitled "OPTICAL CROSSCONNECT SYSTEM" filed on April 28, 2000 by inventors Rajiv Ramaswami, Steve Tabaska, and Robert Ward.

### General Background

Over the last few years, the demand for high-speed communication networks has increased dramatically. In many situations, communication networks are implemented with electrical interconnections. As desired levels of bandwidth and transmission speed for communication networks increase, it will become more and more difficult for electrical interconnections to satisfy these levels.

Optical fiber offers a solution to the difficulties affecting conventional electrical interconnections. For example, optical fiber is less susceptible to inductive or even capacitive coupling effects as electrical interconnections. In addition, optical fiber offers increased bandwidth and substantial avoidance of electromagnetic interference. The potential advantages of optical fiber becomes more important as the transmission rates increase.

Albeit local or global in nature, many communication networks feature hybrid, optical-electrical semiconductor circuits that employ photodetectors, electrical switches, optical modulators and/or lasers. To handle greater data traffic, an alternative approach has been to employ an optical cross-connect switch, which performs switching operations of light pulses or photons (referred to generally as "light signals") without the need for converting and reconvert signals between the optical domain to the electrical domain. However, conventional optical cross-connect switches are still subject to a wide variety of disadvantages.

One disadvantage is that traditional optical cross-connect switches may not offer any protective features against damage to the optical fiber (facility protection) and against equipment failures, namely failures within the optical cross-connect switch itself. One protective feature may be redundancy. Moreover, traditional optical cross-connect switches do not provide one or more of the following: (1) test access capability to non-intrusively monitor the light signals passing through the cross-connect as well as performance monitoring of these light signals; (2) automatic determination of the topology of the communication network; or (3) low-loss bridging capabilities as described below.

### SUMMARY

In general, one embodiment of the present invention relates to a scalable cross-connect switching system and its corresponding method of performing a bridging operation by splitting the incoming light signal into at least a first bridged light signal and a second bridged light signal. The first bridged light signal has a power level equal to or substantially greater than a power level of the second bridged light signal. The disproportionate power levels provide low-loss bridging. Light signals based on these bridged light signals are routed through multiple switch fabrics, which provide redundancy in case of failure by switching within the switch fabric. To detect failures, a test access port may be configured for monitoring multiple optical paths through an optical-to-electrical (O/E) conversion and monitoring device in lieu of test access ports for assigned for each I/O port.

Other aspects and features of the present invention will become apparent to those ordinarily skilled in the art upon review of the following description of specific embodiments of the invention in conjunction with the accompanying claims and figures.

### BRIEF DESCRIPTION OF THE DRAWINGS

The features and advantages of the present invention will become apparent from the following detailed description of the present invention in which:

Figure 1 is a simplified overview of an exemplary embodiment of an optical cross-connect switching system.

Figure 2 is a first exemplary embodiment of an optical cross-connect switching system of Figure 1.

Figure 3 is an exemplary embodiment of the optical fiber switch matrices forming an optical switch core of Figure 2.

Figure 4 is an exemplary embodiment of mirror arrays forming an optical switch matrix of Figure 3.

Figure 5 is an exemplary embodiment of an I/O subsystem featuring a plurality of I/O port modules.

Figure 6 is an exemplary embodiment of a data path for the transfer of light between I/O port modules and multiple fiber optical switch cores of Figure 2.

5        Figure 7 is an exemplary embodiment of a control path featuring the interconnections between the I/O port module and servo modules.

Figure 8 is an exemplary embodiment of the I/O port module of Figures 6 and 7 illustrating a data propagation circuit and a control circuit.

10       Figure 9 is an exemplary embodiment of multiple ports of I/O modules in communication with optical switches controlled by servo modules.

Figure 10 is an exemplary embodiment of an I/O port configured as a test access port.

Figure 11 is an exemplary embodiment of a servo module of the optical cross-connect system of Figure 1.

15       Figure 12 is an exemplary block diagram of a redundant architecture of the optical cross-connect switching system of Figure 1.

Figure 13 is a first exemplary embodiment of a bridging technique associated with an optical cross-connect switching system.

20       Figure 14 is a second exemplary embodiment of a bridging technique associated with an optical cross-connect switching system.

Figure 15 is a third exemplary embodiment of a bridging technique associated with an optical cross-connect switching system.

Figure 16 is an exemplary block diagram of an optical cross-connect switching system utilizing the bridging technique.

25       Figure 17 is an exemplary block diagram of a 1:K Protection Scheme for equipment redundancy.

Figure 18 is a first exemplary embodiment for providing test access functionality through redundancy.

30       Figure 19 is a second exemplary embodiment for providing test access functionality through additional switching.

Figures 20A-20G are exemplary embodiments of an optical cross-connect switching system utilizing a first type of test port/monitor module.

Figure 21 is an exemplary embodiment of an optical cross-connect switching system utilizing a second type of test port/monitor module.

5        Figure 22 is an exemplary embodiment for performance monitoring and topology discovery utilizing a test access port.

Figure 23 is a first exemplary embodiment of a low-loss bridging technique utilized by a first I/O port module under normal operating conditions.

10       Figure 24 is an exemplary embodiment of the low-loss bridging technique of Figure 23 upon failure of an optical switch.

Figure 25 is a second exemplary embodiment of a low-loss bridging technique utilized by a first I/O port module under normal operating conditions.

Figure 26 is an exemplary embodiment of the low-loss bridging technique of Figure 25 upon failure of an optical switch.

15       Figure 27 is a third exemplary embodiment of a low-loss bridging technique utilized by a first I/O port module under normal operating conditions.

#### DETAILED DESCRIPTION

20       Herein, the exemplary embodiments of the present invention relate to a scalable, optical cross-connect switching system and associated techniques to perform bridging and test access functionality in order to protect against facility and equipment failures. These embodiments are not exclusive; rather, they merely provide a thorough understanding of the present invention. Well-known circuits are not set forth in detail in order to avoid unnecessarily obscuring the  
25       present invention.

      Herein, the exemplary embodiments of the present invention relate to a scalable, optical cross-connect switching system. The described embodiments should not limit the scope of the present invention, but rather are intended to provide a thorough understanding of the present invention. Certain well-known  
30       circuits are not set forth in detail in order to avoid unnecessarily obscuring the present invention.

In the following description, certain terminology is used to describe various features of the present invention. For example, a “module” includes a substrate normally formed with any type of material or materials upon which components can be attached such as a printed circuit board or a daughter card for example. Examples of a “component” include an optical switch, a processing unit (e.g., Field Programmable Gate Array “FPGA”, digital signal processor, general microprocessor, application specific integrated circuit “ASIC”, etc.), splitters and the like. A “splitter” is an optical component that performs a bridging operation on an input light signal by splitting that light signal into two or more output light signals. Each module features one or more interfaces to transport information over a link. A “link” is broadly defined as one or more physical or virtual information-carrying mediums that establish a communication pathway such as, for example, optical fiber, electrical wire, cable, bus traces, wireless channels and the like. “Information” can be voice, data, address, and/or control in any representative signaling format such as light signals (e.g., light pulses or photons).

### I. General Architectural Overview

Referring to Figure 1, an exemplary embodiment of a simplified overview of an optical cross-connect switching system 100 is shown. Herein, the optical cross-connect switching system 100 comprises three basic units: a switch subsystem 110, a switch control subsystem 120 and an input/output (I/O) subsystem 130. In one embodiment, the modular architecture of the switch subsystem 110, by a method of having replaceable optical switch cores, provides for switch subsystem maintenance in the event of failure within the switch subsystem 110. It is conceivable that further modularity could be achieved by having replaceable subsections within, thus providing for switch matrix maintenance in the event of failure within a switch matrix itself. The modular architecture of both the switch control subsystem 120 and the I/O subsystem 130, each handling a small number of I/O ports in the system 100, provides scalability to the optical cross-connect switching system 100. Thus, additional I/O ports may



be subsequently added to the optical cross-connect switching system 100 by adding or removing input/output (I/O) port modules (described below).

The switch subsystem 110 includes optical switches for routing light signals. In one embodiment, the optical switches forming the switch subsystem 110 are micro-machined mirrors; however, it is contemplated that other switch fabrics may be used such as liquid crystal technology. The I/O subsystem 130 receives external light signals 140 and transfers these signals to the switch subsystem 110. The switch control subsystem 120 controls the configuration of the switch subsystem 110 (e.g., mirror orientation) and performs certain monitoring functions. The interconnectivity between the switch subsystem 110, the switch control subsystem 120 and the I/O subsystem 130 includes redundancy so that no equipment failures would cause complete disablement of the system 100.

Referring now to Figure 2, a first exemplary embodiment of an optical cross-connect switching system 100 is shown. In general, the optical cross-connect switching system 100 is a matrix-based optical cross-connect with associated I/O port modules. More specifically, the optical cross-connect switching system 100 is collectively formed by a plurality of platforms 205, 206 and 207 in communication with each other, although the implementation of the switching system 100 as a single platform is another embodiment. Herein, each platform 205, 206 and 207 includes a frame 210 (e.g., a rack) that physically supports I/O port modules forming the I/O subsystem 130 as well as servo modules, servo control modules and/or network control modules of the switch control subsystem 120. The modules are arranged either horizontally or vertically within each platform 205, 206 and 207 and can be individually removed or installed without interfering with immediately adjacent modules.

In addition, the frame 210 may also physically support one or more optical switch cores, each including one or more optical switches (e.g., one type of "optical switch" may be two or more mirrors operating in tandem). Herein, a collection of one or more optical switches may also be generally referred to as

“switch fabric.” Thus, the terms switch fabric and optical switch core(s) are interchangeable.

As shown in this embodiment, the first platform 205 comprises (i) a plurality of I/O port modules 215 associated with the I/O subsystem 130 of Figure 1, (ii) a plurality of servo modules 225 and a management control subsystem (MCS) 235 associated with switch control subsystem 120 of Figure 1, and (iii) a first (primary) optical switch core 240 associated with switch subsystem 110 of Figure 1. Similarly, the second platform 206 comprises a plurality of additional I/O port modules 245, a plurality of (redundant) servo modules 250, a management control subsystem 255, and a second (redundant) optical switch core 260. The third platform 207 comprises a plurality of servo modules 265 that control various mirrors of the first and second optical switch cores 240 and 260, which correspond to additional ports associated with I/O port modules 245. Additionally, a light path test signal generator(s), a light path signal monitor(s), circuit breakers and/or alarm visual indication 270 may be located within the third platform 207. For clarity, the elements forming the first platform 205 are described since these elements may be found in the second and/or third platforms 206 and 207.

As shown in both Figures 2-4, the first optical switch core 240 includes a first optical switch matrix 241 and a second optical switch matrix 242. These matrices 241 and 242 are collectively positioned to route light signals 250 between a port of a source I/O port module 215<sub>s</sub> (“s” is a positive whole number) and a port of a destination I/O port module 215<sub>d</sub> (“d” is a positive whole number), both modules located in any of the platforms 205, 206 and 207 as shown in detail in Figure 3. Although a two-bounce routing technique is shown, it is contemplated that a three-bounce routing technique may be used in which the “second bounce” mirror, as optionally shown through dashed lines, is positioned to assist in routing light signals from one optical switch matrix to another.

As shown in Figure 4, one embodiment for each of the optical switch matrices 241 and 242 includes multiple arrays 300 of micro-machined mirrors. Each mirror (e.g., mirror 310) features a mirrored surface 311 and torsional

flexures 320 and 330 that enable the mirror 310 to adjust its physical orientation to reflect incoming light signals in any selected direction. Herein, both the first and second optical switch matrices 241 and 242 include Q micro-machined mirrors, where "Q" is less than or equal to the maximum number of I/O ports that  
5 can be supported by the optical cross-connect switching system 100. For this embodiment, "Q" is greater than or equal to 64 but less than or equal to 1152 ( $64 \leq Q \leq 1152$ ). However, the present invention is not limited to any maximum number of mirrors or I/O ports. It is contemplated, however, that the number of mirrors employed within the first and second optical switch matrices 241 and 242  
10 may differ.

As generally shown in Figures 2, 5 and 6, the plurality of I/O port modules 215 features two groups 216 and 217 of I/O port modules. Each group, such as group 216 or 217 for instance, includes up to seventy-two (72) quad-port I/O port modules as shown in Figure 5 that receive power from one or more power supply  
15 modules denoted herein as "PSM". The components forming an I/O port module is described below and shown in Figures 8 and 9. Thus, each I/O port module, such as I/O port module 215, for example, features an external interface 400 for a plurality of I/O ports 410 (e.g., four I/O ports). An I/O port 410 features a duplex socket that is adapted to receive a duplex pair of optical fiber links, one optical  
20 fiber link routes a light signal to the I/O port 410 while the other routes light signals from the I/O port 410. This support bi-directional optical connections. There is a small percentage (e.g., less than 15%) of these I/O ports, however, that may be assigned as test access ports as described below.

Moreover, as shown in Figure 6, upon receiving an incoming light signal  
25 over an optical fiber link 420, the I/O port module 215, performs a bridging operation by splitting the incoming light signal into multiple (two or more) bridged light signals for routing to the first and second optical switch cores 240 and 260. The bridged light signals are routed through an internal optical interface 425 featuring optical fiber ribbon links 430 and 440. For this embodiment, the  
30 "optical fiber ribbon links" are ribbon cables having multiple optical fiber lines (e.g., two lines from each I/O port). The first optical switch core 240 provides a

primary optical path. The second optical switch core 260 provides a redundant optical path in the event the first optical switch core 240 is not operating properly. The optical switch cores 240 and 260 route the bridged light signals to a selected port of a destination I/O port module (e.g., I/O port module 215<sub>d</sub>) via optical fiber ribbon links 450 and 460.

Upon receiving light signals from both the first and second optical switch cores 240 and 260, the I/O port module 215<sub>s</sub> provides small percentage optical tap signals of the received light paths to the respective servo modules, which in turn determine light signal quality. The respective servo modules will convey light signal quality for each respective light path to the I/O port module, using a digital protocol over an electrical communication link 505 to the I/O port module as shown in Figure 7. The I/O port module 215<sub>s</sub> will in turn, determine (i.e. select) which light signal has the higher signal quality and outputs that signal via interface 400. In most cases, the signal quality of the two light paths presented to the I/O port module will be of the same signal quality and each may have a relatively low optical loss of approximately seven decibel (7 decibels "dB") or less. For instance, a 3dB loss caused by a splitter, approximately 3dB loss caused by an optical switch core and approximately a 1dB loss at an optical switch as described below.

Referring now to Figures 2 and 7, each servo module 225 is configured to receive optical tap signals from one or more I/O port modules. Herein, servo module 225<sub>i</sub> is configured to receive optical tap signals via link 500 from I/O port module 215<sub>s</sub>. These optical tap signals provide feedback to indicate a percentage of the bridged light signals and also allow for light to be injected under certain conditions. In response to receiving optical tap signals via link 500, the servo module 225<sub>i</sub> provides mirror control signals over link 510 to the first optical switch core 240. The mirror control signals are routed via a unique communication path to an optical switch (e.g., a micro-machined mirror) and are associated with the port of the I/O port module 215<sub>s</sub> through which the incoming light signal was routed. The mirror control signals are used for proper adjustment of the physical orientation of the mirror.

The I/O port module 215<sub>d</sub> provides optical tap signals over link 530 to servo module 225<sub>j</sub>. In response to receiving the optical tap signals from I/O port module 215<sub>d</sub>, the servo module 225<sub>j</sub> provides mirror control signals via link 540 to the first optical switch core 240. The mirror control signals are routed via a  
5 unique communication path to a micro-machined mirror associated with a selected port of the I/O port module 215<sub>d</sub> from which the light signal would be output. Herein, sensing the optical tap (feedback) signals, the servo module 225<sub>j</sub> determines the light signal quality and conveys light signal quality information for each light path using a digital protocol over (electrical) link 535. Thereafter, the  
10 I/O port module 215<sub>d</sub> chooses the selected port (i.e. port having the best light signal quality).

Collectively, the optical tap signals, mirror control signals and light signal quality information, which are routed over links 500, 510, 530, 540, 505 and 535, are used by servo modules 225<sub>i</sub> and 225<sub>j</sub> for adjustment of the physical orientation  
15 of mirrors to make a connection between I/O port module 215<sub>s</sub> and 215<sub>d</sub>.

Additionally, I/O port modules 215<sub>s</sub> and 215<sub>d</sub> also transfer optical tap signals via links 520 and 550, respectively. Similar to the above description, these optical tap signals establish the redundant optical path by altering the physical orientation of one or more micro-machined mirrors of the second optical switch  
20 core 260 using mirror control signals over links 560 and 570 and light signal quality information via links 525 and 555.

In the event that no optical power is presented to the I/O port module 215<sub>s</sub>, a substitute light signal may be injected from the servo module 225<sub>i</sub> via link 500. An alignment laser may be used as shown in Figure 11 described below. This  
25 process of light substitution allows for connection establishment and verification when no input light is present to the I/O port module 215<sub>s</sub>. The substitute light source can be within the same wavelength range (e.g. 1100 nanometers "nm" - 1700 nm) as the allowed input light signal range. In one embodiment, the light source or method of injection would be chosen to not interfere with attached  
30 equipment's select operational wavelength range. Choosing a different

wavelength source on the servo module and/or a wavelength specific splitter and/or filter on the I/O port module could do this particular embodiment.

The management control subsystem 235 (see Figure 2) enables communications between two or more servo modules placed within the same or different platforms. The management control subsystem 235 includes at least one servo control module 236 and an optional network control module 238. In one embodiment, the servo control module (SCM) 236 ensures communication between at least servo modules 225<sub>i</sub> and 225<sub>j</sub> that control mirrors associated with the first optical switch core 240. The network control module (NCM) 238 manages the execution of connection configurations for the whole cross-connect switching system and ensures communications between multiple servo control modules 236 and 237. The same architecture is used to control optical switches within the second optical switch core 260 as shown.

## II. General Architecture of the I/O Port Modules

Referring now to Figures 8 and 9, an exemplary embodiment of an I/O port module (e.g., I/O port module 215<sub>s</sub>) and its communications over optical switch cores 240 and 260 is shown. I/O port module 215<sub>s</sub> includes a data propagation circuit 600 for each I/O port and a control circuit 670. Thus, in the event that the I/O port module 215<sub>s</sub> is configured with four I/O ports, four data propagation circuits are implemented on the I/O port module 215<sub>s</sub> as represented. Only the data propagation circuit 600 for one of the I/O ports of I/O port module 215<sub>s</sub> (e.g., i<sup>th</sup> I/O port) is shown in detail for clarity sake.

In one embodiment, the data propagation circuit 600 comprises an optical switch 610, a (passive) splitter 620 and a plurality of tap couplers 630<sub>1</sub>-630<sub>4</sub>. The plurality of tap couplers 630<sub>1</sub>-630<sub>4</sub> correspond to the pairs of optical fibers found in optical fiber ribbon links 430 and 440. The control circuit 670 comprises a programmable memory 680, a processing unit 685 and status identification components 690.

As shown, each port of the I/O port module 215<sub>s</sub> supports full-duplex communications. Thus, an incoming light signal 606 received over port 605 is routed to the splitter 620. The splitter 620 effectively performs a bridging operation by splitting the incoming light signal 606 into bridged light signals 625, which collectively have the same power level (energy) as the light signal 606. In one embodiment, when the splitter 620 is a 50/50 splitter, the bridged light signals 625 have equal power levels. However, it is contemplated that splitter 620 may produce bridged light signals 625 having disproportionate power levels.

The bridged light signals 625 are routed through the tap couplers 630<sub>1</sub> and 630<sub>2</sub>. Attached to servo module 225<sub>i</sub> and servo module 225<sub>i+1</sub> via optical tap links 500 and 520, the tap couplers 630<sub>1</sub> and 630<sub>2</sub> are used to monitor the power level of light signals 635 and 636 propagating through optical fiber ribbon links 430 and 440 (referred to as "outgoing light signals"). This enables the servo modules 225<sub>i</sub> and 225<sub>i+1</sub> to verify the connectivity of the splitter 620 to optical fiber ribbon links 430 and 440 and to detect unacceptable variances in optical performance of the light signal. As shown for this embodiment, the tap couplers 630<sub>1</sub> and 630<sub>2</sub> may separate the bridged light signals into signals having disproportionate power levels in order to maximize the power levels of the outgoing light signals propagating through optical fiber ribbon links 430 and 440. For example, where the tap couplers 630<sub>1</sub> and 630<sub>2</sub> may operate as 90/10 splitters, the outgoing light signals 635 and 636 have ninety (90%) of the total power level of the bridged light signal while the optical tap signals 640 and 641 have only ten percent (10%).

Referring to Figure 8, tap couplers 630<sub>3</sub> and 630<sub>4</sub> are configured to receive incoming light signal 650 and 655 via optical fiber ribbon links 430 and 440, respectively. The tap couplers 630<sub>3</sub> and 630<sub>4</sub> effectively separate the light signals 650 and 655 into corresponding pairs of light signals having disproportionate power levels (e.g., signals 661, 662 and 663, 664). Signals 662 and 664 having the lower power level are provided to the servo module 225<sub>i</sub> and servo module 225<sub>i+1</sub> via links 500 and 520 for monitoring the power levels of the light signals 661 and 663, without the light signals 661 and 663 experiencing substantial signal degradation. The signals 662 and 664 may be light signals that undergo O/E

conversion at the I/O port module 215<sub>s</sub> or at the servo modules 225<sub>i</sub> and 225<sub>i+1</sub> as shown in Figure 11. The tap couplers 630<sub>3</sub> and 630<sub>4</sub> are shown as 90/10 splitters; however, tap couplers 630<sub>3</sub> and 630<sub>4</sub> may be any selected ratio, including 50/50.

5       The light signals 661 and 663 are routed to the optical switch 610 of a destined I/O port. The control circuit 650 on the I/O port module 215<sub>s</sub> determines which of the pair of light signals 661 and 663 has the best signal quality based on conveyed light signal quality information from the servo modules via links 505 and 525 as briefly described below. Parameters used to determine light signal quality include measured optical signal intensity/power, extinction ratio, and the like. The light signal quality information to the I/O port module may be conveyed as failed due to the servo module service operations, high bit error rate, an external light path has failed, and the like. The light signal 661 or 663 with the best signal quality is output through the I/O port 605. Of course, it is contemplated that the light signal output operations described for I/O port i are applicable to I/O port j as shown.

15       It is contemplated that an I/O port of the I/O port module 215<sub>s</sub> may be configured as a test access port. A "test access port" is an I/O port that is used for monitoring light signals routed through another port. Normally, the test access port receives a portion of the power level of a light signal routed through a selected optical switch (e.g., micro-machined mirror). For example, as shown in Figure 10, an I/O port 218 of the I/O port module 215<sub>s</sub> is configured for coupling with a monitoring device 219 (e.g., a bit error rate "BER" monitor in combination with an optical-electrical "O/E" converter, etc.) to monitor a power level of a light signal routed to the i<sup>th</sup> I/O port from an optical switch.

25       Referring back to Figure 8, the control circuit 670 comprises the programmable memory 680 in communication with the processing unit 685 (e.g., FPGA). The programmable memory 680 contains software and other information used by the processing unit 685 to provide selection of the best quality signal based on digital electrical signaling from servo module 225<sub>i</sub> and servo module 225<sub>i+1</sub> over links 505 and 525, respectively. Also, programmable memory 680 includes information used by the processing unit 685 to control the state of the

30



status identification components 690 (e.g., light emitting diodes “LEDs”). The state of the status identification components 690 identifies (1) whether each I/O port is operational and/or (2) whether the I/O port module is operational. The processing unit 685 is further in communications with optical switches of each data propagation circuit employed in the I/O port module 215, in order to receive switch status signals and provide switch control signals. As shown for clarity, processing unit 685 provides optical switch 610 with switch control signals for receiving switch status signals and selecting either light signal 661 or light signal 663.

10

### III. General Architecture of the Servo Modules

Referring now to Figure 11, an exemplary embodiment of the servo module (e.g., servo module 225;) is shown. In one embodiment, the servo module 225; comprises two separate modules in communication over connectors 705 and 790. These separate modules are referred to as an “optical detector module” 700 and a “servo mirror control module” 750.

15

The optical detector module 700 comprises a first processing unit 710, memory 715, a plurality of detection/modulation (DM) circuits 716 and status identification components 717. As shown, the optical detector module 700 features sixteen (16) DM circuits 716 to support four (4) quad-port I/O port modules. Each DM circuit 716 includes an analog-to-digital (A/D) converter 720, a laser 725, optical-electrical (O/E) detectors 730 and 731, and optional amplifiers 735 and 736.

20

The servo mirror control module 750 comprises a second processing unit 755, a memory 760, a plurality of mirror signal detection and generation (SDG) circuits 761, a third processing unit 775 and status identification components 795. The SDG circuits 761 correspond in number to the DM circuits 716 of the optical detector module 700. Each SDG circuit 761 features an A/D converter 765, a digital-to-analog (D/A) converter 770, hinge position sensors 780-781 and high voltage (HV) mirror drivers 785-786.

25

30

As shown in Figure 11, the optical detector module 700 is removably coupled to the servo mirror control module 750. This allows the optical detector module 700 to be "hot swapped" from a backplane, which features connectors 705 and 790 connecting the optical detector module 700 to the servo mirror control module 750, without disrupting the servo mirror control module's 750 ability to hold the mirrors in their existing positions for an extended period of time. This "hot swapping" of the optical detector module 700 allows for repair or upgrade of the optical detector module 700. Optical detector module 700 receives optical tap (feedback) signals 640 and 662 from one or more I/O port modules (e.g., I/O port module 215, via link 500) and can transmit optical control signals 726 from the laser 725 for alignment of light signals transferred between two I/O port modules. The optical tap signal 640 is based on an input light signal that is routed to the switch fabric.

More specifically, with respect to servo module 225<sub>i</sub>, the O/E detectors 730 and 731 are coupled to tap couplers 630<sub>1</sub> and 630<sub>3</sub> of Figures 8-9. More specifically, the O/E detectors 730 and 731 are configured to detect incoming, optical tap signals 640 and 662, convert the optical tap signals 640 and 662 into corresponding electrical control signals measuring a power level of the outgoing light signal, and optionally route the electrical control signals to corresponding amplifiers 735 and 736. The (amplified) electrical control signals are provided to the A/D converter 720. The A/D converter 720 converts the electrical control signals into measured power sense signals 644 of a digital form. The measured power sense signals 644 are provided to the first processing unit 710.

Herein, the first processing unit 710 may perform a number of operations based on the electrical control signals such as threshold crossing, LOS integration, input/output power ratio analysis and the like. Software and other information necessary for performing these operations may be obtained from the memory 715 by the first processing unit 710. Herein, memory 715 can be non-volatile memory such as non-volatile random access memory, electrically erasable programmable read only memory (EEPROM) and the like.

The optical detector module 700 includes multiple status identification components 717 (e.g., light emitting diodes "LEDs"). A first LED 718 identifies whether any operational faults associated with the servo module 225<sub>i</sub> have occurred. A second LED 719 indicates when the optical detector module 700 is in  
5 service.

Referring still to Figure 11, in this embodiment, the servo mirror control module 750 comprises the second processing unit 755 that is coupled to both the first processing unit 710 and the third processing unit 775. For instance, in order to adjust the switch fabric in response to the measured power sense signals 644,  
10 the second processing unit 755 receives information representative of the measured power sense signals from the first processing unit 710 via connectors 705 and 790. The second processing unit 755 further receives information representative of measured power sense signals for the light signal at a targeted I/O port. This information is provided by the SCM 236 over link 580 via the third  
15 processing unit 775. This assists in reducing errors in adjusting the torsional flexures of the mirrors.

Upon receipt of these measured power readings, the second processing unit 755 controls a particular SDG circuit corresponding to a mirror associated with the I/O port over which the tapped light signal was routed. The control  
20 involves slight mirror orientation adjustments if the power level readings differ substantially.

In particular, a first hinge position sensor 780 senses a position of a mirror via link 510 from the first optical switch core 240. The sensed position signal is routed to the A/D converter 765, which is subsequently placed in a digital format  
25 before routing to the second processing unit 755. When the servo module 225<sub>i</sub> is adjusting the switch fabric, the second processing unit 755 transfers mirror control signals to the D/A converter 770. The mirror control signals are routed to HV driver 785 and applied to a selected mirror of the first optical switch core in order to adjust the amount of torsional flexure along a first dimensional plane (e.g., X-  
30 axis). This is accomplished to minimize the loss experienced by the light signal.

A second hinge position sensor 781 senses a position of a mirror for the first optical switch core along a second dimensional plane (e.g., Y-axis). The sensed position signal is routed to the A/D converter 765, which is subsequently placed in a digital format before routing to the second processing unit 755. When the servo module 225<sub>i</sub> is adjusting the switch fabric, the second processing unit 755 transfers mirror control signals to the D/A converter 770. The mirror control signals are routed to HV driver 786 and are applied to the selected mirror of the first optical switch core in order to adjust the amount of torsional flexure along the second dimensional plane. The specifics of the hinge position sensors 780 and 781 are described in a PCT application entitled "Micromachined Members Coupled for Relative Rotation By Torsional Flexure Hinges" (International Publication No. WO 00/13210) published on or around March 9, 2000.

In another embodiment, when I/O port module 215<sub>s</sub> is the destination of a light signal, the second processing unit 755 receives information representative of the measured power sense signals associated with the optical tap signal 662 that has been analyzed by the first processing unit 710. The optical tap signal 662 is based on an output light signal being routed from an I/O port. In this situation, the third processing unit 775 receives information associated with the measured power sense signals from a source I/O port as reported by SCM 236 over link 580.

20

#### IV. Redundant Architecture of the Optical Cross-Connect Switching System

Referring now to Figure 12, a block diagram of an alternative embodiment of the architecture of the optical cross-connect switching system of Figure 1 is shown which includes redundant protection capabilities. Redundancy is desired in order to increase the reliability of such an optical cross-connect switching system. Aside from the I/O port modules, all other modules are duplicated to obtain the desired redundancy. Thus, it is necessary for light signals from a source I/O port module 215<sub>s</sub> to be routed to a destination I/O port module 215<sub>d</sub> through two optical paths, namely a primary optical path 800 using a first optical

30

switch core 240 and a redundant optical path 810 using a second optical switch core 260.

With respect to the primary optical path 800, a servo module 225<sub>i</sub> is connected to both the source I/O port module 215<sub>s</sub> and the first optical switch matrix (not shown) of the first optical switch core 240. In particular, the servo module 225<sub>i</sub> controls the physical orientation of a mirror of the first optical switch matrix that corresponds to the source I/O port module 215<sub>s</sub>. To establish and maintain the primary optical path 800 for the light signal, the servo module 225<sub>i</sub> needs to communicate with other servo modules such as servo module 225<sub>j</sub>. Thus, a servo control module (SCM) is implemented to support such communications, possibly through a time-slot switching arrangement.

As shown, the SCMs 236<sub>1</sub>-236<sub>2</sub> are also duplicated so that each servo module 225 is connected to at least two SCMs 236<sub>1</sub>-236<sub>2</sub>. Thus, in the event that the SCM 236<sub>1</sub> fails, the primary optical path 800 remains intact because communications between the servo modules 225<sub>i</sub> and 225<sub>j</sub> are maintained via redundant SCM 237<sub>1</sub>. The transfer is accomplished by temporarily halting the adjustment of (i.e. freezing) the mirrors inside the first optical switch core 240 while control is transferred from SCM 236<sub>1</sub> to SCM 237<sub>1</sub>. The SCMs 236<sub>1</sub> and 237<sub>1</sub> associated with the first optical switch core 240 are in communication via a network control modules (NCMs) 238<sub>1</sub> and 238<sub>2</sub> for example.

With respect to the redundant optical path 810, a servo module 225<sub>i+1</sub> is connected to both the source I/O port module 215<sub>s</sub> and one or more mirror(s) of a first optical switch matrix (not shown) of the second optical switch core 260. Another servo module 225<sub>j+1</sub> is connected to both the destination I/O port module 215<sub>d</sub> and one or more mirror(s) of a second optical switch matrix (not shown) of the second optical switch core 260. The orientation of these mirrors produces the redundant optical path 810.

To establish and maintain the redundant optical path 810 for the light signal, a SCM 236<sub>2</sub> may be implemented with a dedicated time-slot switching arrangement in order to support continuous communications between the servo module and another redundant servo module associated with the destination I/O

port module. As shown, the SCM 236<sub>2</sub> is also duplicated so that each servo module 225<sub>i+1</sub> and 225<sub>j+1</sub> is connected to at least two SCMs 236<sub>2</sub> and 237<sub>2</sub>. Thus, the redundant optical path 810 is maintained even when one of the SCMs 236<sub>2</sub> and 237<sub>2</sub> fails. The SCMs 236<sub>2</sub> and 237<sub>2</sub> associated with the second optical switch core 260 communicate via the first NCM 238<sub>1</sub> and the second NCM 238<sub>2</sub>,  
5 respectively. The second NCM 238<sub>2</sub> is in communication with the first NCM 238<sub>1</sub> to allow all SCMs and servo modules to communicate for coordination of the primary optical path 800 and the redundant optical path 810.

10 V. Detailed Overview of the Bridging Technique for the Optical Cross-Connect Switching System

Referring now to Figures 13-16, exemplary embodiments of the bridging technique for redirecting signals to prevent against disruption of an optical path of  
15 the optical cross-connect switching system due to facility or equipment failures is shown.

A first exemplary embodiment of a bridging technique utilized by a source I/O port module 900 is shown in Figure 13. In particular, a port 905 of the source I/O port module 900 receives a light signal 910 and subsequently routes the light  
20 signal 910 to one or more splitters 920. For clarity sake, one or more splitters are referred to in a singular tense as "splitter".

Herein, the splitter 920 effectively produces two outgoing light signals with generally equivalent power (energy) levels, which are routed over links 925 and 930. In one embodiment, the collective power level measured for the  
25 outgoing light signals is generally equal to the power level of the light signal 910 minus the additional energy loss caused by the splitter 920 (e.g., approximately 3dB).

The two outgoing light signals are subsequently routed over links 925 and 930 over to different inputs of a switch fabric 935. In one embodiment, the switch  
30 fabric 935 may be an optical switch core formed with two optical switch matrices of micro-machined mirrors as described above. However, it is contemplated that

the particular configuration of the switch fabric 935 is not relevant to the inventive bridging technique described below.

The switch fabric 935 routes the outgoing light signals over links 940 and 945 to a switch 950 within a destination I/O port module 955. The optical switch  
5 950 is configured to select one of the light signals received over links 940 and 945 based on any number of signal quality parameters such as measured optical signal intensity/power, extinction ratio, and the like. Of course, it is contemplated that certain I/O port modules (e.g., modules 960 and 970) may be implemented within the optical cross-connect switching system but devoid of any bridging  
10 functionality.

As shown in Figure 14, a second exemplary embodiment of a bridging technique utilized by the source I/O port module 900 to separate the original light signal 910 into multiple outgoing light signals which are routed to multiple optical switches is shown. In particular, the port 905 of the source I/O port module 900  
15 receives the light signal 910 and subsequently routes the light signal 910 to the splitter 920. For this embodiment, the splitter 920 effectively produces at least two outgoing light signals with generally equivalent power (energy) levels routed over links 925 and 930. Link 925 provides a first outgoing light signal to the switch fabric 980 while link 930 provides a second outgoing light signal to  
20 another switch fabric 985. Herein, in this embodiment, each switch fabric 980 or 985 includes a switching technology, possibly optical switch matrices as described above. The switch fabric 980 and 985 may be one or more optical switches in the same optical switch core or different optical switch cores.

In response to receiving the first outgoing light signal, the switch fabric  
25 980 routes the same over link 940 to the optical switch 950. The switch fabric 985 routes the second outgoing light signal over link 945 to the optical switch 950. Coupled to both links 940 and 945, the optical switch 950 is configured to select one of the outgoing light signals received over links 940 and 945 based on a number of parameters such as those described above.

30 Referring now to Figure 15, a third exemplary embodiment of a bridging technique associated with an optical cross-connect switching system is illustrated.

The optical cross-connect switching system (OXC) 1000 comprises one or more optical input ports 1001A-1001N and one or more optical output ports 1002A-1002N provided by the various I/O port modules. The optical cross-connect switching system 1000 includes I/O port modules 1004A-1004N and 1004A'-1004M' that provide bridging for the switch fabric 1010. Bridging means that at least two optical paths are provided between I/O port modules carrying the same light signals. The switch fabric 1010 illustrates exemplary optical signal paths 1015A-1015D and redundant optical signal paths 1015A'-1015D'. If one optical path fails in the switch fabric 1010, the redundant optical path in the switch fabric 1010 continues to handle the data carried by the light signals. For example, if the optical path 1015A fails in the switch fabric 1010, the optical path 1015A' continues to carry the light signals. The redundant optical path 1015A' can be thought as bridging a gap in the optical path 1015A when it fails.

An optical path (fiber break) or the generation of light signals in an optical path (component failure) can fail, terminating the light signal completely or generating bit errors at a high rate over that of the other light signal or optical path. By monitoring the light signal inputs and/or outputs from the optical cross-connect switching system 1000, for example, a determination can be made whether to switch from one light signal in one optical path to another. The optical path and/or light signal in the optical path can fail for a variety of reasons including one or more faulty components or a failure in control.

To generate a redundant optical path in the optical cross-connect switching system 1000, an incoming light signal is input into an input port such as input port 1001A. In one type of I/O port module, illustrated as I/O port module 1004A-1004N (generally referred to as 1004), the incoming light signal is coupled into an optical-to-electrical-to-optical "O/E/O" converter 1007 (referred to as "O/E/O") in the input optical path 1011. The O/E/O 1007 converts the light signal into an electrical signal, which is then converted back into a light signal. The electrical signal is used to monitor the incoming light signals.

In general, the O/E/O 1007 is coupled to an optical splitter 1008 to split the incoming light signal into at least two outgoing light signals on at least two



(split) optical paths 1021A and 1022A. The optical splitter 1008 can be used to split the light signal into more than two split optical paths to provide greater redundancy and reliability if desired but is typically not needed. The optical splitter 1008, in one embodiment, is a passive optical coupler. While the data  
5 signal or pulses of light of the split light signals are the same, the energy level of the incoming light signal can be split equally or unequally into the at least two light signals on the at least two split optical paths 1021A and 1022A.

The at least two split optical paths 1021A and 1022A proceed to the switch fabric 1010 and switched to another I/O port module respectively over the  
10 optical paths 1015A and 1015A' for example. The redundant light signals in the optical paths 1015A and 1015A' are routed into a switch 1009 of the I/O port module 1004B for example over the split paths 1023B and 1024B, respectively. The switch 1009 is an optical switch. As its output, the switch 1009 selects between the at least two outgoing light signals routed over split optical paths  
15 1015A and 1015A'. The selected output of the switch 1009 is routed into the optical output path 1012 of the I/O port module 1004B and the output port 1002B of the optical cross-connect switching system 1000. In the case that one of the two light signals over split optical paths 1015 and 1015A' fails or has errors, the switch 1009 can select the alternate optical path as its output to overcome the path  
20 failure or the errors.

In another type of I/O port module, illustrated by I/O port modules 1004A'-1004M' (generally referred to as 1004'), an incoming light signal at the input port 1001C is first routed into a splitter 1008' in the optical input path 1011. The incoming light signal is split by the splitter 1008' into at least two light  
25 signals routed over at least two (split) optical paths 1021C and 1022C for example. The at least two light signals on the at least two split optical paths 1021C and 1022C are then provided to the switch fabric 1010 for switching. In the switch fabric 1010, the split light signals are routed over different optical paths such as optical paths 1015C and 1015C'. The split light signals over optical paths  
30 1015C and 1015C' are routed into the same switch of an I/O port module such as

switch 1009' of the I/O port module 1004M' via the optical paths 1023M and 1024M for example.

As shown, the switch 1009' is an optical switch. As its output, the switch 1009' selects between the at least two light signals in the at least two split optical paths 1015C and 1015C' for example. The selected output of the optical switch 1009' is routed into the optical output path 1012 of the I/O port module 1004M' and the output port 1002M of the optical cross-connect switching system 1000. In the case that one of the two light signals in the at least two split optical paths fails or has errors, the optical switch 1009' can select the alternate optical path as its output to overcome the path failure or the errors. The output of the optical switch 1009' is coupled into the O/E/O 1007' on the I/O port module 1004M' for regenerating the light signals. With the O/E/O 1007' in the output path, regeneration is performed post split. In this manner, the O/E/Os do not need to be duplicated in the input path and output path for each connection of a communication channel over the optical cross-connect switching system 1000.

The monitoring provided by the O/E/Os 1007 and 1007' in the I/O port modules 1004A-1004N and 1004A' -1004M' in the optical cross-connect switching system 1000, assist in the selection between the at least two light signals in the at least two split optical paths by the optical switches 1009 and 1009', respectively. If the monitoring determines that there is no signal at the output of the optical switch 1009' and it is known that there should be a signal present, the optical switch 1009' can select the alternate path. If the monitoring determines that there is an incoming light signal into the splitter 1008 and it is known that it should be present at the output of the optical switch 1009, the alternate path can be selected.

In either case, the I/O port modules of the optical cross-connect switching system 1000 of Figure 15 split the incoming light signal at an input port into at least two (split) outgoing light signals to propagate over two different optical paths and provide redundancy in how the data signal is routed over the switch fabric 1010. The I/O port modules then select which of the at least two (split)

outgoing light signals to route into an output port of the optical cross-connect switching system 1000.

Referring now to Figure 16, a block diagram of an optical cross-connect switching system 1000 is illustrated. The optical cross-connect switching system 1000 is an alternate embodiment to provide bridging over a switch fabric 1110. The optical cross-connect switching system 1000 has one or more optical input ports 1101A-1101N and one or more optical output ports 1102A-1102N provided by the various I/O port modules.

Using one type of I/O port module, an incoming light signal 1111 is first converted from a light signal in the optical domain into an electrical signal in the electrical domain and fanned out (e.g., electrically split into two equal electrical signals) by coupling to two optical transmitters 1118A and 1118B (e.g., an electrical-to-optical "E/O" converter such as a semiconductor laser). The two optical transmitters 1118A and 1118B convert in parallel the electrical signal into two light signals in the optical domain. The two light signals generated by the two optical transmitters 1118A and 1118B are substantially similar.

The two light signals are then routed through the switch fabric 1110 through differing optical paths 1115A and 1115A'. A selection is then made at the output of the switch fabric 1110 between the two light signals in order to generate the output light signal 1112 from the optical cross-connect switching system 1000. If one path of the two light signals should fail, the opposite path is selected.

Using another type of I/O port module, namely I/O port module 1104A',..., or 1104M', the incoming light signal is optically split into two split light signals which are routed over the switch fabric 1110. At the output of the switch fabric 1110, the two (split) light signals in the optical domain are coupled into two optical receivers 1128A and 1128B (each an optical to electrical "O/E" converter such as a photodiode) to convert them into two electrical signals respectively in the electrical domain. The two electrical signals are then coupled into multiplexer 1129 to electronically select which one of the two should be transmitted out the output port 1102M of the optical cross-connect switching

system 1000 by an optical transmitter 1127 (e.g., an E/O converter such as a semiconductor laser). The optical transmitter 1127 converts the selected electrical signal in the electrical domain into a light signal in the optical domain.

As shown in Figure 16, the optical cross-connect switching system 1000  
5 can include one or more I/O port modules 1104A-1104N and/or one or more I/P port modules 1104A'-1104M'. In either case, the I/O port modules provide two different optical paths through the optical switch fabric 1110 for the same communication channel connection. For example, optical paths 1115A-1115D are one path for the communication channels while optical paths 1115A'-1115D'  
10 are another both carrying the same data signals. If one optical path should fail generating a gap in the connection, the other path is selected to bridge the gap and to allow a continuous flow of data for the given communication channel connection. Bridging in this manner increases the reliability of the optical cross-connect switching system 1000.

15 The I/O port modules 1104A-1104N include an optical receiver 1117 (e.g., an O/E converter such as a photodiode) which is coupled to a pair of optical transmitters 1118A and 1118B (e.g., an electrical-to-optical "E/O" converter such as a semiconductor laser) in the input path 1111. Thus, in the input path 1111 of the I/O port modules 1104A-1104N, an optical-electrical-optical conversion  
20 (O/E/O) is performed. In the output path 1112, the I/O port modules 1104A-1104N include an optical switch 1109 to select between two light signals. The optical transmitters 1118A and 1118B generate the two parallel light signals that are routed over two paths in the switch fabric 1110 such as optical paths 1115A and 1115A'. The optical switch 1109 selects between the two parallel light  
25 signals to generate one as the output of the optical cross-connect switching system 1000 on an output port. If the selected path should fail, the optical cross-connect switching system 1000 switches to the other light signal carried over the other optical path.

30 The I/O port modules 1104A'-1104M' include an optical splitter 1108 in the input path 1111 to split the incoming light signal into two (split) outgoing light signals. The two outgoing light signals are routed to the switch fabric 1110 over

two separate optical paths. For example, the I/O port module 1104A' would be coupled for routing the split, outgoing light signals over optical paths 1115C and 1115C' of the switch fabric 1110. In the output path 1112, the I/O port module 1104A'-1104M' include the pair of optical receivers 1128A and 1128B, the  
5 multiplexer 1129, and the optical transmitter 1127 as previously described.

The pair of optical receivers 1128A and 1128B (e.g., an O/E converter such as a photodiode) receive the (split) light signals routed over the two separate optical paths 1115C and 1115C'. A benefit of locating these receivers after the switch fabric(s) 1110 is that they can accept a full range of wavelengths of  
10 photons due to dual wave-length division multiplexed (DWDM) light signals. The wide range of wavelengths of light signals over the optical paths in the optical cross-connect switching system 1000 can exist due to DWDM. Being able to cross-connect any light signal to the O/E/O over a range of wavelengths is desirable to provide wavelength conversion/translation in the optical cross-  
15 connect switching system 1000.

Another benefit is that if some negative optical conditions or negative timing parameters exist in the cross connected light signal from the switch fabric, such as low optical power, wrong wavelength, poor spectral quality, overpower, etc. within the cross-connect switching system, it can be isolated by the O/E/O  
20 before being output to the network. The split light signals are converted into two electrical signals by the optical receivers 1128A and 1128B and routed into the multiplexer 1129. The two electrical signals can also be monitored locally to determine which should be selected to generate the output light signal. It can also be forced to switch by means of external communication control, if external  
25 monitoring methods are employed. The multiplexer 1129 electronically selects one of the two electrical signals to be coupled into the optical transmitter 1127 (an E/O converter such as a semiconductor laser). If the two signals being selected from have the same data and protocol, as expected, it is envisioned that the monitored switching between the two within the multiplexer 1129 could be  
30 hitless, i.e. produce no errors on the selected electrical signal. This behavior is very beneficial to bridge and roll applications and those that have Forward-Error-

Correction data encoding schemes. This would also apply to SONET and SONET like data streams as well as those employing a 'wave wrapper' protocol. The optical transmitter 1127 converts the selected electrical signal in the electrical domain into a light signal in the optical domain for transmission out over the  
5 output port 1112 of the optical cross-connect switching system 1000. Thus, in the output path 1112 of the I/O port module 1104A'-1104M', an optical-electrical-optical conversion (O/E/O) is performed.

Bridging in this manner provides that if an optical path or a component in the path fails, the other path and components can handle the data flow over the  
10 communication channel in the optical cross-connect switching system 1000. A disadvantage to the bridging provided by the different embodiments of the optical cross-connect switching system 1000 of Figures 15 and 16 is that fewer communication channels can be supported because of the redundant optical paths formed in the switch fabrics 1010 and 1110 respectively. One way to alleviate  
15 this problem is to use a redundant switch fabric to provide the redundant path.

#### VI. 1:K Protection Scheme for Equipment Redundancy

As previously described above, one technique for providing equipment  
20 redundancy is to implement two or more switch fabrics, each receiving a bridged, light signal. A better copy (higher power level) of the bridged, light signals is selected as the output light signal. Alternatively, as shown in Figure 17, if a single optical switch (or switch port) is more likely the cause for failure than the entire switch fabric 1300, then a 1:K protection scheme may be employed.

25 Herein, for every K switch ports 1310<sub>1</sub>-1310<sub>K</sub>, an additional switch port 1320 of the switch fabric 1300 is designed as a spare port. For this embodiment, "K" is a positive whole number. The particular value for K is based on a design choice and the selected degree of switch reliability for the optical cross-connect switching system. For example, a maximum redundancy is where one or more  
30 additional ports are reserved for each switch port. A minimum redundancy is where one additional switch port is reserved for a large number of switch ports.

As further shown in Figure 17, K incoming light signals along input optical paths 1330<sub>1</sub>-1330<sub>K</sub> are bridged by splitters 1340<sub>1</sub>-1340<sub>K</sub> within one or more I/O port modules. Based on an incoming light signal, one outgoing light signal is routed along a primary optical path 1350, represented by optical paths 5 1350<sub>1</sub>-1350<sub>K</sub>, to corresponding switch ports 1310<sub>1</sub>-1310<sub>K</sub> of the switch fabric 1300. The other outgoing light signal is routed along a secondary optical path 1360, represented by optical paths 1360<sub>1</sub>-1360<sub>K</sub>, to a corresponding port of an optical (K:1) switch fabric 1370. The optical switch fabric 1370 includes K switch inputs and one switch output that is coupled to additional switch port 1320 10 via link 1380.

In accordance with the switching architecture described above, in the event that one of the optical switches associated with the primary optical path 1350<sub>1</sub>-1350<sub>K</sub> fails, a decrease in power is sensed from the routed light signal. This decrease in power is used to trigger the change from the switch port 15 1310<sub>1</sub>,...1310<sub>K</sub> associated with the failed optical switch to the additional switch port 1320.

## VII. Test Access Functionality

20 Test access is a function by which a signal flowing through an optical switch can be monitored in a non-intrusive manner through a switch port designated for this purpose. Herein, certain embodiments for performing test access are described, although it is contemplated that other embodiments may be developed in accordance with the spirit of the invention.

25 Referring now to Figure 18, a first exemplary embodiment for providing test access functionality through redundancy is shown. An incoming light signal is bridged by a splitter 1405 at a source I/O port module 1400 to produce a first and second outgoing light signals. The first outgoing light signal is routed to a first switch fabric 1410 via link 1420 while the second outgoing light signal is 30 routed to a second switch fabric 1430 via link 1440. Herein, in one embodiment,

the first switch fabric 1410 is part of a first optical switch core. The second switch fabric 1430 is part of a second optical switch core.

Shown as an illustrative example, the first outgoing light signal is selected by a switch 1460 at a destination I/O port module 1450 to be output. The other  
5 light signal, namely the second outgoing light signal, is routed to a test access port 1470 associated with the second optical switch 1430. Furthermore, an input port on the second optical switch 1430 can also be dedicated to test signal injection for further testing functionality. An O/E monitoring device 1480 may be coupled to the test access port 1470 (as represented in dashed lines) to analyze the incoming  
10 light signal and perhaps the operations of the second optical switch 1430 itself.

Referring to Figure 19, a second exemplary embodiment for providing test access functionality through additional switching is shown. Herein, incoming light signals over input paths  $1510_1$ - $1510_N$  are routed through I/O port modules  $1500_1$ - $1500_N$ . More specifically, the incoming light signals are bridged by  
15 splitters  $1520_1$ - $1520_N$  of the I/O port modules  $1500_1$ - $1500_N$  and one output of each I/O port module  $1500_1$ - $1500_N$  is sent into a (NxN) switch fabric 1530. All other outputs are routed to a unique switch port of a Nx1 switch fabric 1540. The Nx1 switch fabric 1540 features a single output port 1550 being designated as the test access port. An O/E converter and monitoring device may be coupled to the test  
20 access port 1550 to analyze the light signals routed from splitters  $1520_1$ - $1520_N$ . This Nx1 switch fabric 1540 could potentially also be part of the larger switch core.

Referring now to Figures 20A-20G and 21, block diagrams of exemplary embodiments of an optical cross-connect switching system 1000 utilizing a test  
25 access port is illustrated. The optical cross-connect switching system 1000 include I/O port modules 1604-1604N that provide bridging by using two (optical) switch fabrics (also referred to as optical switch cores) 1610A and 1610B. An incoming signal is split into at least two bridged, light signals with one portion being routed into one switch fabric 1610A with another portion of the  
30 signal being routed into the other switch fabric 1610B. While one switch fabric 1610A acts as the "active" switch fabric, the other switch fabric 1610B acts as a



“redundant” switch fabric. Providing a redundant switch fabric also provides reliability in case there is a problem in control of one of the switch fabrics.

Furthermore, the redundant switch fabric 1610B provides hot swapability in that while one is having its switch fabric or other control systems updated or replaced, the other can continue to provide optical switching. The optical cross-connect switching system 1000 also includes a test port/monitor module 1605 to test and monitor the optical paths through the two switch fabrics 1610A and 1610B in order to detect equipment or facility failures.

More specifically, as shown in Figure 20A, the optical cross-connect switching system 1000 includes the first switch fabric 1610A, the second switch fabric 1610B, and one or more I/O port modules. These I/O port modules provide one or more optical input ports 1601A-1601N and one or more optical output ports 1602A-1602N as shown. The optical cross-connect switching system 1000 can also include one or more different types of I/O port modules such as one or more I/O port modules 1604A-1604N (generally referred to as 1604) and/or one or more I/O port modules 1604A'-1604M' (generally referred to as 1604'). The optical cross-connect switching system 1000 can also include one or more test port/monitor modules 1605.

The I/O port modules 1604A-1604N provide an O/E/O converter (referred to as “O/E/O”) 1607 in their input paths while the I/O port modules 1604A'-1604M' provide an O/E/O 1607' in their output paths. The I/O port modules 1604A-1604N and 1604A'-1604M' each have an optical splitter 1608 and 1608' respectively in their input paths. The I/O port modules 1604A-1604N and 1604A'-1604M' each have an optical switch 1609 and 1609' respectively in their output paths. The O/E/Os 1607 and 1607', optical switches 1609 and 1609', and the optical splitters 1608 and 1608' are optically coupled together within the I/O port modules 1604A-1604N and 1604A'-1604M' as shown and illustrated in Figures 20A and 20B.

In either type of I/O port modules 1604 or 1604', the optical splitter 1608 or 1608' splits the incoming light signal into at least two outgoing light signals. These outgoing light signals are routed over different optical paths, one of which

is routed to the first switch fabric 1610A and the other which is routed to the second switch fabric 1610B. In either type of I/O port modules 1604 or 1604', the optical switch 1609 and 1609' selects a light signal from the two outgoing light signals having the better signal quality over two differing optical paths, one of which is received from the first switch fabric 1610A and the other of which is received from the second switch fabric 1610B. In this manner, should an optical path in one of the two switch fabrics 1610A or 1610B fail for any reason, the optical switch 1609 or 1609' only need select the opposite signal path.

For example, as an illustration, consider the exemplary optical path 1615A in the first switch fabric 1610A and the optical path 1615A' in the second switch fabric 1610B. The splitter 1608 in the I/O port module 1604A splits an incoming light signal into at least two outgoing light signals on optical paths 1621A and 1622A. The light signal on the optical path 1621A is routed into the first switch fabric 1610A and the signal on the optical path 1622A is routed into the second switch fabric 1610B. The switch fabrics 1610A and 1610B route these light signals over exemplary optical paths 1615A and 1615A' respectively.

The optical path 1615A in the switch fabric 1610A is coupled into the optical path 1623N which is coupled into the optical switch 1609 of the I/O port module 1604N. The optical path 1615A' in the switch fabric 1610B is routed to the optical path 1624N, which in turn is routed into the optical switch 1609 of the I/O port module 1604N. In one case, the optical switch 1609 of the I/O port module 1604N selects the light signals over the optical path 1615A so that the first switch fabric 1610A is acting as the active switch fabric.

In another case, the optical switch 1609 of the I/O port module 1604N selects the light signals over the optical path 1615A' so that the second switch fabric 1610B is acting as the active switch fabric. If either optical switch fabric fails generating a gap, the other is automatically selected by the I/O port modules to bridge the gap.

For this illustration, light signals from the I/O port module 1604A are coupled into the I/O port module 1604N such that only one O/E/O 1607 is needed to regenerate the light signals input into the optical cross-connect switching

system 1000. If it is desirable to regenerate light signals into as well as out of the optical cross-connect switching system 1000, light signals from one of the I/O port modules 1604A-1604N can be coupled into one of the I/O port modules 1604A'-1604M' which have an O/E/O 1607' to regenerate the output light signals  
5 in the output path.

Other I/O port modules can be used with more than one switch fabric to provide redundancy. Figures 20B-20G illustrate exemplary embodiments of other combinations of I/O port modules that can be used with the two (optical) switch fabrics 1610A and 1610B.

10 Referring now to Figure 20B, the cross-connect switching system 1000 includes I/O port modules 1104A-1104N, I/O port modules 1104A'-1104M', test port/monitor module 1605, network control module (NCM) 1606, first (optical) switch fabric 1610A, and second (optical) switch fabric 1610B. The elements of I/O port modules 1104A-1104N and I/O port modules 1104A'-1104M' were  
15 previously discussed with reference to Figure 16. The optical cross-connect switching system 1000 provides redundancy but uses differing I/O port modules having different components.

Referring now to Figure 20C, the optical cross-connect switching system 1000 includes I/O port modules 1644A-1644N, I/O port modules 1644A'-  
20 1644M', test port/monitor module 1605, network control module (NCM) 1606, first switch fabric 1610A, and second switch fabric 1610B. I/O port modules 1644A-1644N and I/O port modules 1644A'-1644M' utilize optical switches 1628 and 1628' as opposed to splitters 1608 and 1608' in I/O port modules 1604A-1604N and 1604A-1604M' respectively which were previously described.  
25 Optical switches 1628 and 1628' provide less optical power loss than the splitters 1608 and 1608' so that a stronger light signal can be routed through the switch fabric.

Referring now to Figure 20D, the optical cross-connect switching system 1000 includes I/O port modules 1654A-1654N, I/O port modules 1654A'-  
30 1654M', test port/monitor module 1605, network control module (NCM) 1606, first switch fabric 1610A, and second optical switch fabric 1610B. I/O port

modules 1654A-1654N and I/O port modules 1654A'-1654M' utilize optical switches 1628 and 1628' and optical couplers 1629 and 1629' as opposed to splitters 1608 and 1608' and optical switches 1609 and 1609' in I/O port modules 1604A-1604N and 1604A'-1604M' respectively which were previously described.

- 5    Optical switches 1628 and 1628' provide less optical power loss than the splitters 1608 and 1608'. Optical couplers 1629 and 1629' act similar to a multiplexer and can be passive so that no switching control is required.

Referring now to Figure 20E, the optical cross-connect switching system 1000 includes I/O port modules 1654A-1654M, passive I/O port modules 1653A-1653N, test port/monitor module 1605, network control module (NCM) 1606,  
10    first switch fabric 1610A, and second switch fabric 1610B. I/O port modules 1654A-1654M utilize optical switches 1628 and optical couplers 1629 as opposed to splitters 1608 and optical switches 1609 in I/O port modules 1604A-1604N respectively which were previously described. Each of the passive I/O port  
15    modules 1653A-1653N includes the optical switch 1628 in the input path and the optical coupler 1629 in the output path as shown. Each of the I/O port modules 1653A-1653N does not have an O/E/O in either its input path or its output path. That is, optical cross connect switching providing at least one redundant switch fabric can also use these types of passive I/O port modules to reduce the number  
20    of O/E/Os and lower costs.

Referring now to Figure 20F, alternate combinations of different types of I/O port modules within an optical cross-connect switching system having at least one redundant optical switch fabric is shown. In Figure 20F, the optical cross-connect switching system 1000 includes I/O port modules 1604A'-1604M',  
25    passive I/O port modules 1663A-1663N, test port/monitor module 1605, network control module (NCM) 1606, first switch fabric 1610A, and second switch fabric 1610B. I/O port modules 1604A'-1604M' were previously described with respect to Figure 20A. Each of the passive I/O port modules 1663A-1663N includes an optical splitter 1668 in the input path and an optical switch 1669 in the output path  
30    as shown. Each of the passive I/O port modules 1663A-1663N does not have an O/E/O in either their input path or their output path.

Referring now to Figure 20G, another embodiment of combinations of different types of I/O port modules is illustrated for an optical cross-connect switching system having a redundant (optical) switch fabric. In Figure 20G, the optical cross-connect switching system 1000 includes I/O port modules 1604A'-1604M', one or more I/O port modules 1663 and 1670, test port/monitor module 1605, network control module (NCM) 1606, first switch fabric 1610A, and second switch fabric 1610B. The I/O port modules 1604A'-1604M' were previously described with respect to Figure 20A. The I/O port module 1663 includes an optical splitter 1668 in the input path and an optical switch 1669 in the output path as shown. The I/O port module 1670 provides only a flow through optical path between input and output ports and the switch fabrics 1610A and 1610B. Each of the I/O port modules 1663 and 1670 are deemed "passive" because they do not have an O/E/O in either their input path or their output path.

While other combinations of I/O port modules and (optical) switch fabrics can be formed, it is desirable to provide light signal regeneration by routing a light signal over an optical path through the optical cross-connect switching system so that at least one O/E/O conversion occurs to the light signal to increase the optical power level at the output from what was received at the input. The O/E/O conversion may be used for other reasons as well which were previously described. If it is desirable, a signaling channel previously described between the optical cross connect switch and attached network or client equipment can be used to provide information regarding signal conditions and performance of and around the optical cross-connect switch. The signaling channel is particularly desirable if nothing but passive I/O port modules without O/E/Os are used in channels of the optical cross-connect switch.

The optical cross-connect switching system 1000 having redundant switch fabrics can readily provide self testability. The optical cross-connect switching system 1000 can optionally include a test port/monitor module 1605 in order to test the optical paths through the first and second switch fabrics 1610A and 1610B to perform sophisticated performance monitoring and attach test equipment if needed. One port of either switch fabric 1610A or 1610B can be dedicated as a

test access port. The test port/monitor module 1605 is inserted into the dedicated test access port and monitors one of the split signals to determine if there is a failure in the optical path or not as well as to determine performance measures for the light signal including a bit error rate (BER). Any incoming light signal  
5 passing through the optical cross-connect 1000 can be accessed and monitored by switching one of the split signals over to the test access port where the test port/monitor module 1605 is present. The other part of the split signal continues to be routed through the optical cross-connect switching system 1000 unaffected. The test access port and test port/monitor module 1605 allow non-intrusive  
10 monitoring of the incoming light signals.

As shown in Figure 21, the test port/monitor module 1705 includes an optical switch 1719 and an optical-to-electrical (O/E) converter 1717. The O/E 1717 couples to a controller (e.g., a NCM 1606) within the optical cross-connect 1000 via link 1711 in order to process the electrical signals from the test  
15 port/monitor module 1705 representing the light signal of the tested optical path. The optical switch 1717 selects between monitoring an optical path of the first switch fabric 1610A and an optical path of the second switch fabric 1610B. The switch fabric which is being monitored can be referred to as the "redundant switch fabric", while the switch fabric that is being used to carry data over the  
20 communication channel connection is referred to as the "active switch fabric". In Figure 21, the second switch fabric 1610B is being monitored.

The test port selects a port to monitor to determine if a light signal is actually present on the split optical paths and if so, if the optical path carrying the data in the first switch fabric is reliable or has failed. The signals can also be  
25 monitored to determine what is the bit error rate through the optical cross-connect switching system 1000. The test port/monitor module 1605 or 1705 steps from path to path to sample the signals on the paths to determine where a failure may occur. The test port/monitor module 1605 or 1705 can use an algorithm such as a round robin algorithm to test each path in sequence. If a faulty path is detected,  
30 the test port/monitor module 1605 or 1705 raises an alarm and the information is

sent to a network control module, for further fault isolation and servicing of the failure.

5 The test port/monitor module 1605 or 1705 can also ping-pong from one switch fabric to another in order to alternate the testing process. In Figure 20A, the second optical switch fabric 1610B is being monitored by the optical path 1626 using a first test input port. Referring momentarily to Figure 21, the first switch fabric 1610A is being monitored by the optical path 1625 using a second test input port as opposed to the second switch fabric 1610B to illustrate the ping-pong between switch fabrics 1610A and 1610B. Either of the test port/monitor  
10 module 1605 or 1705 can step from path to path to sample the signals over the optical paths to determine where a failure may occur. If a faulty optical path is detected, an alarm is signaled and it is removed from available paths in the respective switch fabric until its repaired or the redundant switch fabric is selected to replace the failing path.

15 Referring now to Figures 20A and 21, the test port/monitor module 1605 illustrated in Figure 20A monitors incoming light signals for either switch fabric. The test port/monitor module 1705 illustrated in Figure 21 can monitor incoming light signals from either switch fabric 1610A or 1610B as well as generate its own optical test signal to actively self-test optical paths through the either switch  
20 fabric. In addition to the O/E 1717 and the optical switch 1719, the test port/monitor module 1705 includes an electrical-to-optical (E/O) converter 1718 (e.g., a semiconductor laser) to generate a test light signal which is controlled to actively test optical paths through the first and second optical fabrics 1610A and 1610B. The test port/monitor modules 1605 or 1705 can be used in any  
25 configuration of an optical cross-connect switching system including the single and dual switch fabric embodiments disclosed herein.

VIII. Detailed Overview of Performance Monitoring and Topology Discovery for the Cross-Connect Switching System

Referring now to Figure 22, an exemplary embodiment for performance  
5 monitoring and topology discovery utilizing a test access port is shown. Incoming light signals are routed over input paths  $1810_1$ - $1810_N$  to I/O ports associated with I/O port modules  $1800_1$ - $1800_N$  of the optical cross-connect switching system 1000. Upon receipt, the incoming light signals undergo a bridge operation by splitters  $1820_1$ - $1820_N$ . Each splitter  $1820_1, \dots, 1820_N$  produces one bridged light  
10 signal to an optical switch core 1830 and another bridged light signal to an optical switch 1840. The optical switch 1840 includes N input ports and a single output port 1850 that is designated as the test access port. For example, the optical switch 1840 may be any Nx1 switching device or an Nx1 optical switch core with a single I/O port 1850 as the test access port.

15 An O/E converter and monitoring device 1860 (e.g., a test port/monitor module) may be coupled to the test access port 1850 to analyze light signals routed from any of the splitters  $1820_1$ - $1820_N$ . For example, under normal operations, outgoing light signals are sent through the optical switch core 1830 and, at the optical switch 1840, each input I/O port is switched periodically to  
20 route its input light signal to the test access port 1850 for monitoring purposes. So, a single O/E converter and monitoring device 1860 can cycle among all the I/O ports and periodically monitor each one sequentially or randomly. The technique can be extended to support more than one test access port and multiple O/E converter and monitoring devices that cycle through the signal passing  
25 through the optical switch 1840.

The same technique can also be used for topology discovery. For example, each light signal passing through the optical cross-connect switching system 1000 is provisioned with an identifier (or a path trace). In particular, the light signal can be provisioned with an identifier by method of inserting a known  
30 byte or series of bytes in the light signal data stream. This identifier is provisioned in external equipment, e.g., the source of the data. It can also be



encoded by low frequency modulation (sometimes referred to as “pilot tones”) that ride on top of generic light paths (protocol of the data is not important in this case). This can be done by various methods, not excluding the optical cross-connect switching system itself. The optical cross-connect switching system can discover identifier information during monitoring by the servo module for instance. Once the information is read and discovered, the optical cross-connect switching system can report connectivity information for a portion of an optical network, commonly called topology discovery. Constant and or periodic monitoring for this type of information would constitute topology tracking.

Detected using the monitoring scheme described above, the path trace can be used to enable the system to identify a set of connections within the network and track these connections.

#### IX. Detailed Overview of the Bridging Technique for the Optical Cross-Connect Switching System

Referring now to Figures 23-27, exemplary embodiments of the bridging technique for redirecting signals to prevent against disruption of the optical path due to link or equipment failures is shown.

As shown in Figure 23, a first exemplary embodiment of a low-loss bridging technique utilized by a first I/O port module 1900 is shown. In particular, a port 1905 of the I/O port module 1900 receives a light signal over link 1910 and subsequently routes the light signal to a splitter 1920. Herein, the splitter 1920 effectively performs a bridging operation to produce two bridged, outgoing light signals. Under normal operating conditions, a first outgoing light signal is associated with a substantial percentage of the power of the incoming light signal routed over link 1910. At the same time, a second outgoing light signal has a power level that is less than the first outgoing light signal but sufficient enough so that it can be monitored non-intrusively. For example, the splitter 1920 may split a light signal where the first outgoing light signal is associated with ninety percent (90%) of the power while the second outgoing light

signal is associated with ten percent (10%) of the power. Of course, any disparate power levels may be used such as 80/20, 75/25 and the like.

All outgoing light signals are subsequently passed to a switch 1930 which routes the outgoing light signals over links 1940 and 1945 to different groups of  
5 optical switch cores 1950 and 1955. The optical switch cores 1950 and 1955 (e.g., a pair of micro-machine mirrors, etc.) route the first outgoing light signal over link 1960 to an optical switch 1970 within a second I/O port module 1980 while the second outgoing light signal is routed over link 1965 to the optical switch 1970. The optical switch 1970 is configured to select one of the outgoing  
10 light signals received over links 1960 and 1965 based on any number of light signal quality parameters. The non-selected outgoing light signal may be monitored non-intrusively for test access purposes via a test access port as described above.

Referring now to Figure 24, upon detection of a failure of the optical  
15 switch core 1950, the switch 1930 is configured to re-route the first outgoing light signal over link 1945 and the second outgoing light signal over link 1940, respectively. This allows the first outgoing light signal to be routed to the optical switch 1970 via the second optical switch core 1955 that is fully operational.

Alternatively, as shown in Figures 25 and 26, it is contemplated that a  
20 two-state 1x2 switch 1990 may be utilized in lieu of the splitter 1920 and switch 1930 combination of Figures 23 and 24. Under normal operations, the switch 1990 may be configured to route an outgoing signal corresponding to a high percentage (e.g.,  $P\%$ , where  $P > 50$ ) of power from the incoming light signal to the first optical switch core 1950. A lower percentage (e.g.,  $100 - P\%$ ) of power from  
25 the incoming light signal is routed to the second optical switch core 1955. Upon detection of a failure of the first optical switch core 1950, the switch 1990 is configured to re-route the first outgoing light signal over link 1945 and the second outgoing light signal over link 1940. This allows the first outgoing light signal to be routed to the optical switch 1970 via the second optical switch core 1955 that is  
30 fully operational.

Alternatively, as shown in Figure 27, it is contemplated that a polarization beam splitter 1995 may be utilized in lieu of the 1 x 2 switch of Figures 25 and 26. Under normal operations, the beam splitter 1995 splits an input light signal into two resultant light signals, a first resultant light signal having a first  
5 orthogonal state of polarization (e.g., horizontal) and a second resultant light signal having a second orthogonal state of polarization (e.g., vertical).

For example, the first orthogonal state of polarization is associated with a higher level of power than the second orthogonal state of polarization. Upon detection of a failure of the first optical switch core 1950, the beam splitter 1995  
10 is configured to re-route the first resultant light signal having a first orthogonal state of polarization over link 1945 and the second outgoing light signal having a second orthogonal state of polarization over link 1940. This allows the first outgoing light signal to be routed to the optical switch 1970 via the second optical switch core 1955 that is fully operational.

15 While certain exemplary embodiments have been described and shown in the accompanying drawings, it is to be understood that such embodiments are merely illustrative of and not restrictive on the broad invention, and that this invention not be limited to the specific constructions and arrangements shown and described, since various other modifications may occur to those ordinarily skilled  
20 in the art. For example, the present invention has been described in detail using an optical cross-connect switching system. However, the present invention may be implemented into other optical network equipment that accept optical data signals including an optical bridge, an optical router, an optical hub, an optical node, an optical concentrator, or other networking equipment accepting a data  
25 signal embodied in a light signal. Additionally, it is possible to implement the present invention or some of its features in hardware, firmware, software or a combination thereof where the software is provided in a processor readable storage medium such as a magnetic, optical, or semiconductor storage medium.

CLAIMS

What is claimed is:

- 1           1.     A method comprising:  
2           receiving an incoming light signal having a predetermined power level;  
3     and  
4           performing a bridging operation by splitting the incoming light signal into  
5     at least a first outgoing light signal routed over a first optical data path and a  
6     second outgoing light signal routed over a second optical data path, the second  
7     outgoing light signal to monitor for disruption of the first optical data path.
- 1           2.     The method of claim 1, wherein the first outgoing light signal and  
2     the second outgoing light signal have a collective power level substantially equal  
3     to the predetermined power level.
- 1           3.     The method of claim 2, wherein the collective power level of the  
2     first outgoing light signal and the second outgoing light signal is equal to the  
3     predetermined power level minus a power loss caused by the splitting of the  
4     incoming light signal.
- 1           4.     The method of claim 1, wherein the first outgoing light signal  
2     having a power level substantially greater than a power level of the second  
3     outgoing light signal.
- 1           5.     The method of claim 4 further comprising:  
2           providing the second outgoing light signal to a multiple input optical  
3     switch; and  
4           selecting outputting a signal input into the multiple input optical switch for  
5     analysis by an optical-to-electrical conversion and monitoring device.

1           6.       The method of claim 5 further comprising:  
2           selecting the second outgoing light signal for output from an optical switch  
3           of a destination I/O port module when the first optical path is disrupted.

1           7.       An input/output (I/O) port module comprising:  
2           a substrate; and  
3           a splitter mounted to the substrate, the splitter to receive an incoming light  
4           signal, produce a first bridged light signal and a second bridged light signal as a  
5           redundant light signal in order to increase reliability of information transmissions  
6           in an optical domain.

1           8.       The I/O port module of claim 7, wherein the substrate is a printed  
2           circuit board including a first interface to receive the incoming light signal over an  
3           optical fiber link.

1           9.       The I/O port module of claim 7, wherein the first bridged light  
2           signal and the second bridged light signal produced by the splitter have  
3           substantially equal power levels.

1           10.      The I/O port module of claim 7, wherein the first bridged light  
2           signal and the second bridged light signal produced by the splitter have  
3           substantially disproportionate power levels.

1           11.      The I/O port module of claim 7 further comprising a first tap  
2           coupler coupled to the splitter, the first tap coupler to separate the first bridged  
3           light signal into a first outgoing light signal and a first optical tap signal for use in  
4           monitoring a power level of the first outgoing light signal.

1           12.      The I/O port module of claim 11, wherein the first outgoing light

2 signal and the first optical tap signal produced by the first tap coupler have  
3 substantially disproportionate power levels.

1 13. The I/O port module of claim 11 further comprising a second tap  
2 coupler coupled to the splitter, the second tap coupler to separate the second  
3 bridged light signal into a second outgoing light signal and a second optical tap  
4 signal for use in monitoring a power level of the second outgoing light signal.

1 14. The I/O port module of claim 8 further comprising an optical  
2 switch to select one of the at least two light signals received over the second  
3 interface.

1 15. The I/O port module of claim 14 further comprising an optical-to-  
2 electrical converter to convert the one of the at least two light signals from an  
3 optical domain to an electrical domain for signal analysis.

1 16. The I/O port module of claim 15 further comprising an electrical-  
2 to-optical converter for injecting a test signal to actively test an optical path  
3 through a remotely located switch fabric.

1 17. A scalable optical cross-connect switching system, comprising:  
2 a switch fabric;  
3 a first input/output (I/O) port module including (i) a splitter to receive an  
4 incoming light signal and produce a first and second bridged light signals from the  
5 incoming light signal, (ii) a first tap coupler to receive the first bridged light signal  
6 to produce a first optical tap signal and a first outgoing light signal and (iii) a  
7 second tap coupler to receive the second bridged light signal to produce a second  
8 optical tap signal and a second outgoing light signal; and  
9 a second I/O port module including an optical switch to receive the first  
10 and second outgoing light signals and to select one of the first and second

11 outgoing light signals for output from the second I/O port module.

1 18. The optical cross-connect switching system of claim 17 further  
2 comprising:  
3 a first optical link coupled to the first I/O port module, the first optical link  
4 to propagate the incoming light signal; and  
5 a second optical link coupled to the second I/O port module, the second  
6 optical link to propagate the selected one of the first and second outgoing light  
7 signals.

1 19. The optical cross-connect switching system of claim 17, wherein  
2 the first optical tap signal and the first outgoing light signal have substantially  
3 equal power levels.

1 20. The optical cross-connect switching system of claim 19, wherein  
2 the second optical tap signal and the second outgoing light signal have  
3 substantially equal power levels.

1 21. The optical cross-connect switching system of claim 17, wherein  
2 the first optical tap signal and the first outgoing light signal have substantially  
3 disproportionate power levels.

1 22. The optical cross-connect switching system of claim 17, wherein  
2 the switch fabric includes an optical switch core.

1 23. The optical cross-connect switching system of claim 17 further  
2 comprising at least one additional I/O port module where the first I/O port module  
3 and the at least one additional I/O port module collectively are K I/O port  
4 modules, where K is greater than or equal to two.

1           24.     The optical cross-connect switching system of claim 23, wherein  
2     the switch fabric comprises  
3           a first optical switch core to receive K first outgoing signals from the K  
4     I/O port modules and a switch port; and  
5           a second optical switch core including K switch inputs and one switch  
6     output to communicate information to the switch port of the first optical switch  
7     core.

1           25.     The optical cross-connect switching system of claim 17, wherein  
2     the switch fabric includes  
3           a first switch fabric to receive the first outgoing light signal; and  
4           a second switch fabric to receive the second outgoing light signal for  
5     routing to the optical switch of the second I/O port module and a switch port  
6     dedicated for injection of a test signal to be read from a test access port of the  
7     second switch fabric.

1           26.     The optical cross-connect switching system of claim 23, wherein  
2     the switch fabric comprises  
3           an optical switch core to receive K first outgoing signals from the K I/O  
4     port modules; and  
5           a Kx1 optical switch core including K switch inputs and one switch output  
6     to communicate information to an optical-to-electrical converter and monitoring  
7     device.

1           27.     A scalable optical cross-connect switching system, comprising:  
2     a first optical switch core;  
3     a second optical switch core; and  
4     a first input/output (I/O) port module including (i) at least one splitter to  
5     receive an incoming light signal and produce a first and second outgoing light



6 signals from the incoming light signal, and (ii) a switching device to receive the  
7 first and second outgoing light signals and to route the first outgoing light signal  
8 to the first optical switch core and the second outgoing light signal to the second  
9 optical switch core when the first optical switch core is fully operational; and  
10 a second I/O port module including an optical switch to receive the first  
11 and second outgoing light signals and to select the first outgoing light signal for  
12 output when the optical switch core is fully operational.

1 28. The optical cross-connect switching system of claim 27, wherein  
2 the second outgoing light signal is routed from a test access port of the second  
3 optical switch core during normal operation.

1 29. The optical cross-connect switching system of claim 27, wherein  
2 the optical switch of the second I/O port module selects the second outgoing light  
3 signal for output when the first optical switch core is non-operational.

1 30. The optical cross-connect switching system of claim 29, wherein  
2 the first outgoing light signal is routed from a test access port of the second  
3 optical switch core when the first optical switch core is non-operational.

1 31. The optical cross-connect switching system of claim 27, wherein  
2 the switching device is an optical switch.

1 32. The optical cross-connect switching system of claim 27, wherein  
2 the switching device is a beam splitter.

1 33. A scalable optical cross-connect switching system, comprising:  
2 a switch fabric including a first optical switch core and a second optical  
3 switch core;  
4 a first input/output (I/O) port module coupled to the first optical switch

5 core and the second optical switch core, the I/O port module including a switch to  
6 (i) receive an incoming light signal, (ii) split then incoming light signal into a first  
7 light signal and a second light signal and (iii) route the first light signal via the  
8 first optical switch core along a first optical path and the second light signal via  
9 the second optical switch core along a second optical path, the first light signal  
10 having a power level greater than the second light signal; and

11 a second I/O port module including an optical switch to receive the first  
12 and second outgoing light signals and to select the first outgoing light signal for  
13 output from the second I/O port module.

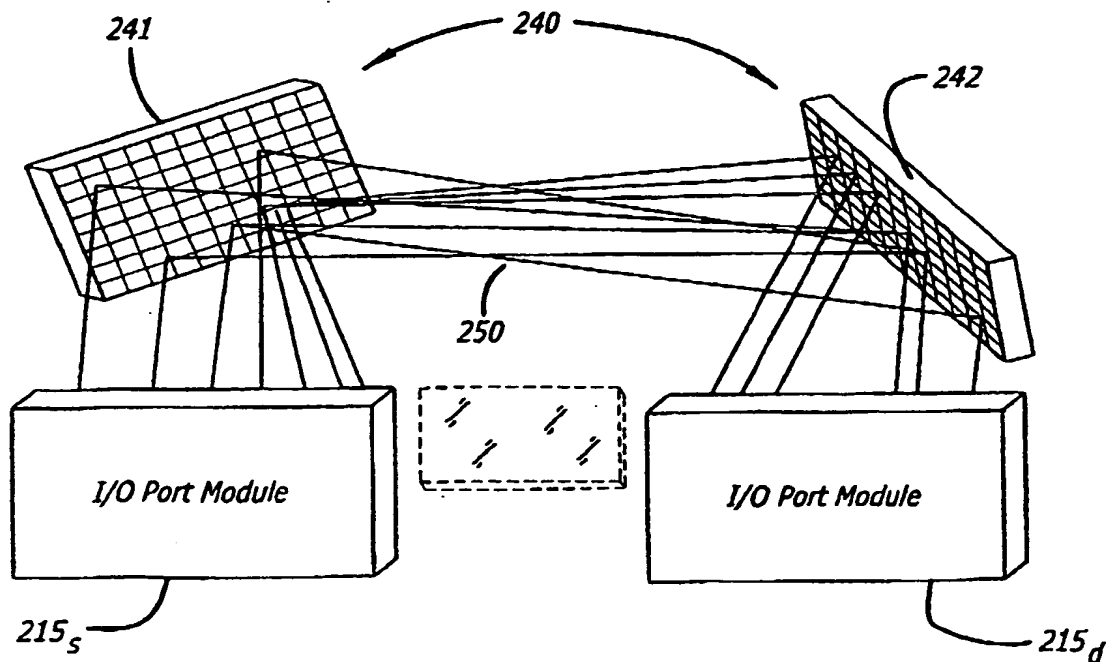
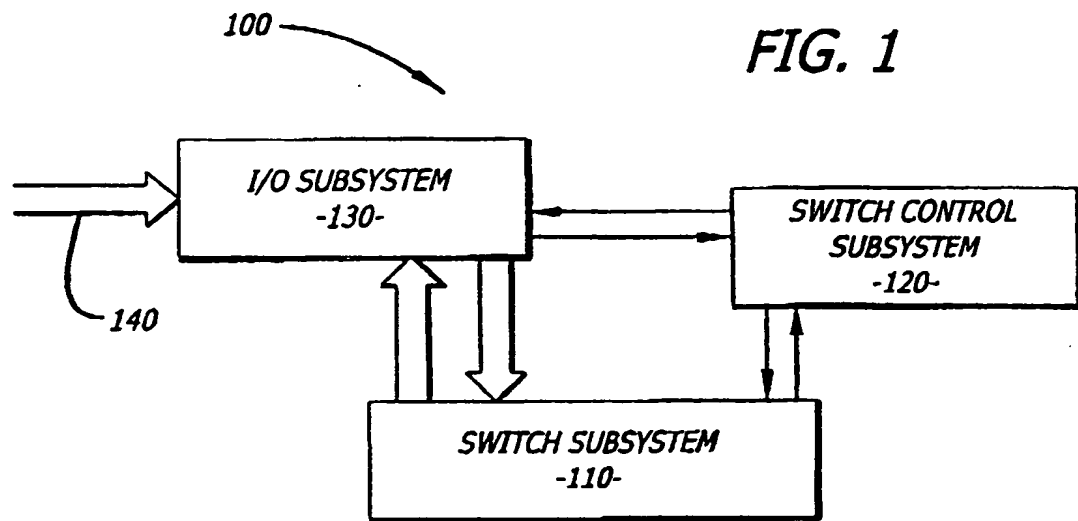
1 34. The optical cross-connect switching system of claim 33, wherein  
2 the second outgoing light signal is routed from a test access port of the second  
3 optical switch core.

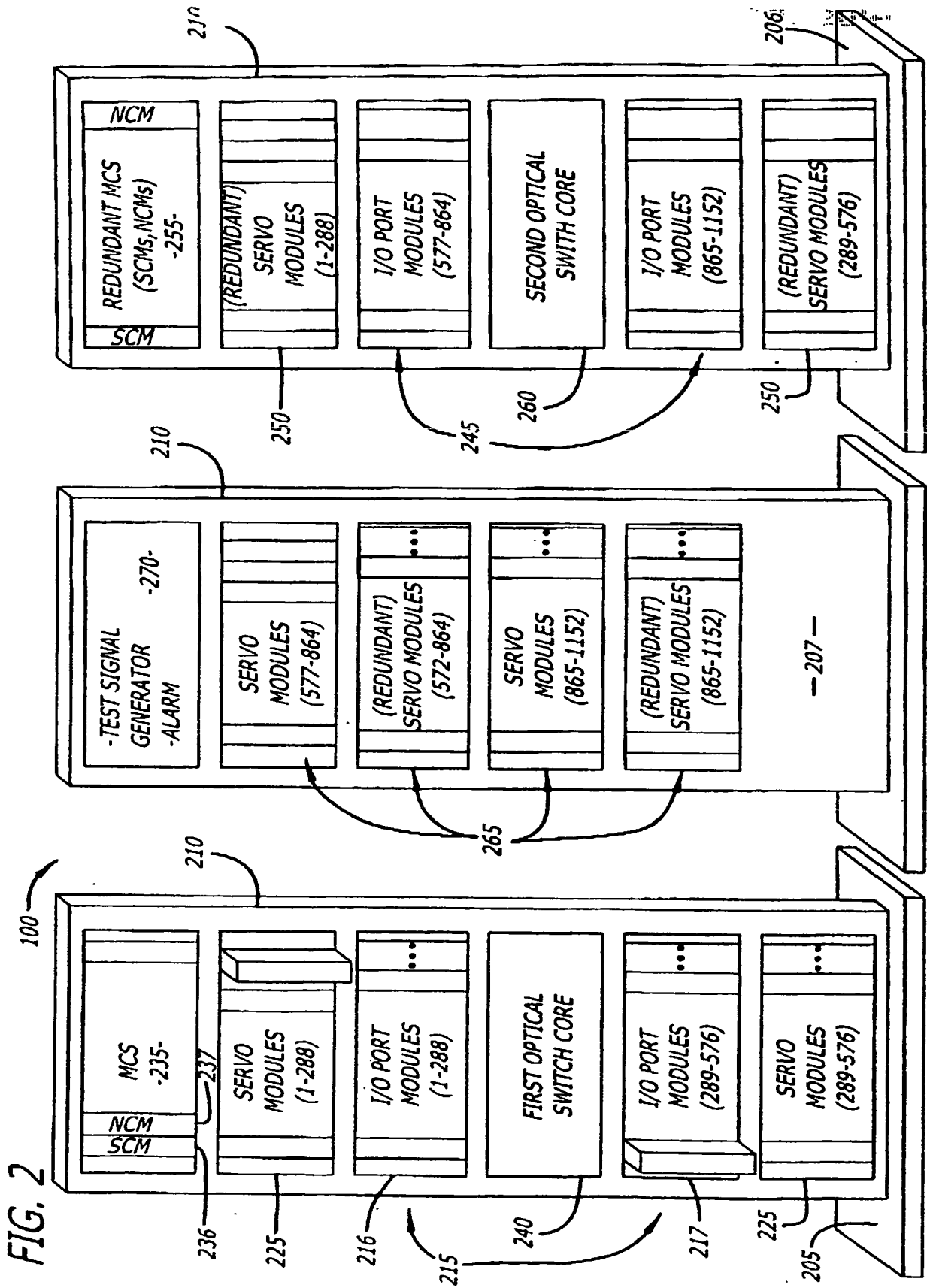
1 35. The optical cross-connect switching system of claim 33, wherein  
2 the optical switch of the second I/O port module selects the second outgoing light  
3 signal for output when the first optical path is disrupted.

1 36. The optical cross-connect switching system of claim 35, wherein  
2 the first outgoing light signal is routed from a test access port of the second  
3 optical switch core when the first optical switch core is non-operational.

1 37. The optical cross-connect switching system of claim 33, wherein  
2 the first outgoing light and the second outgoing light signal have substantially  
3 equal power levels.

1 38. The optical cross-connect switching system of claim 33, wherein  
2 the first outgoing light signal and the second outgoing light signal have  
3 substantially disproportionate power levels.

**FIG. 3**



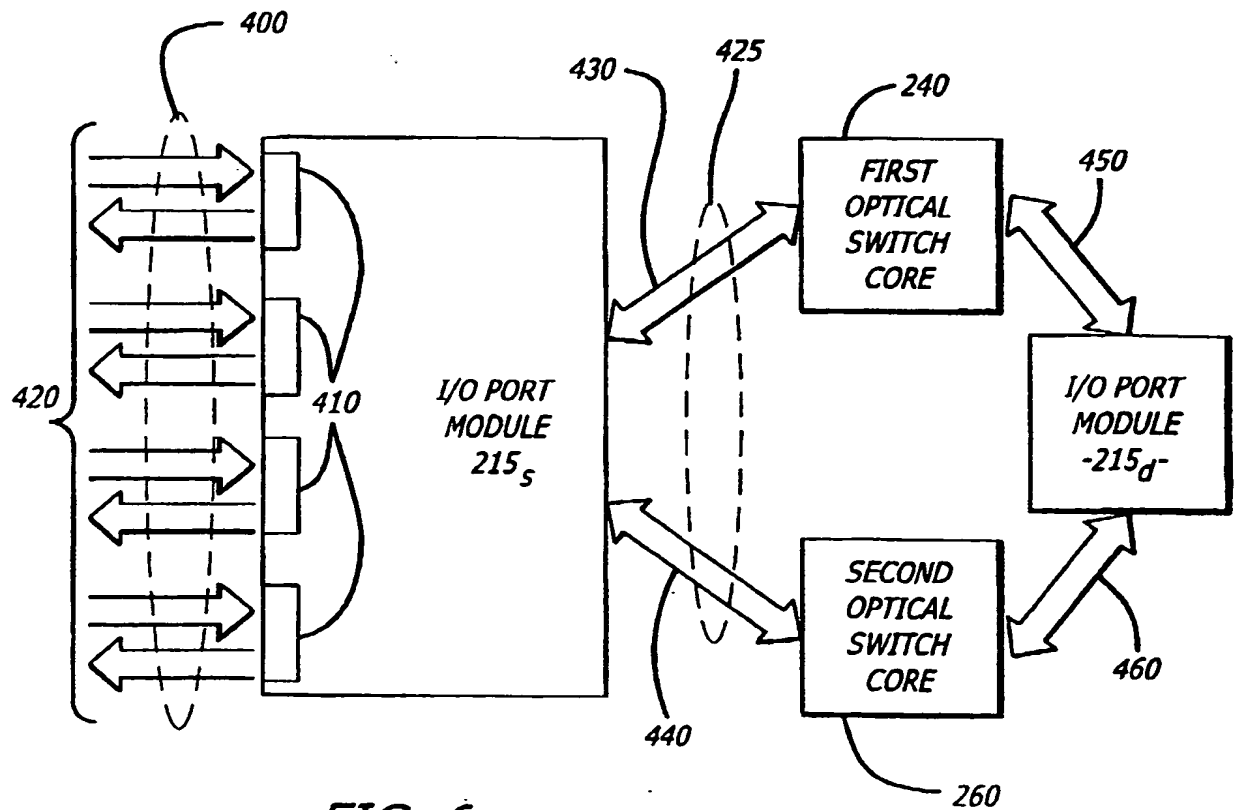
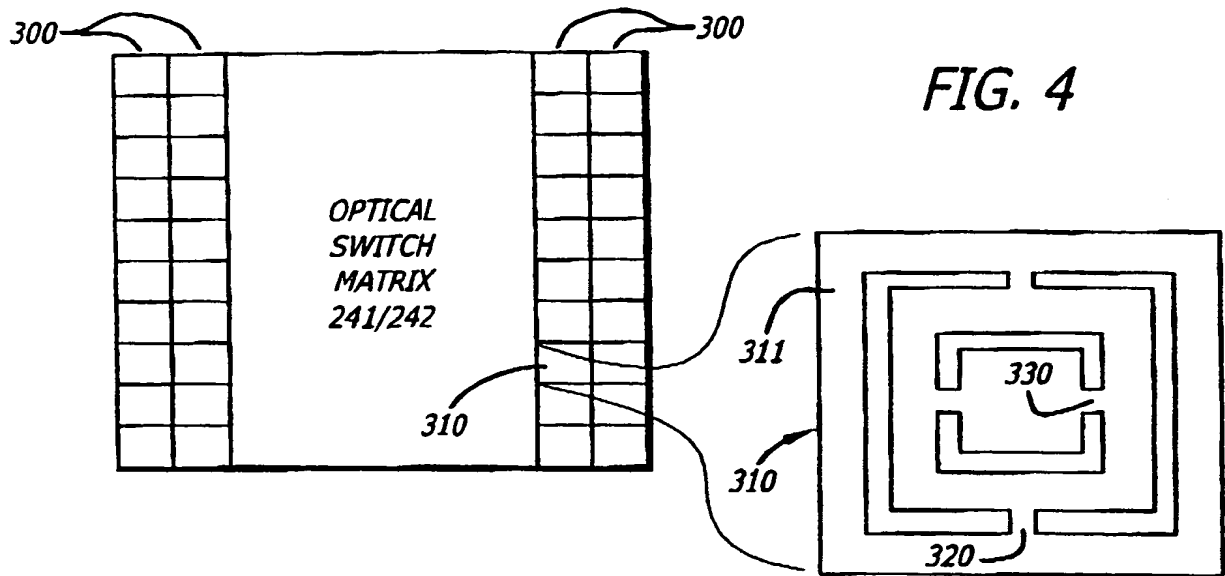


FIG. 6

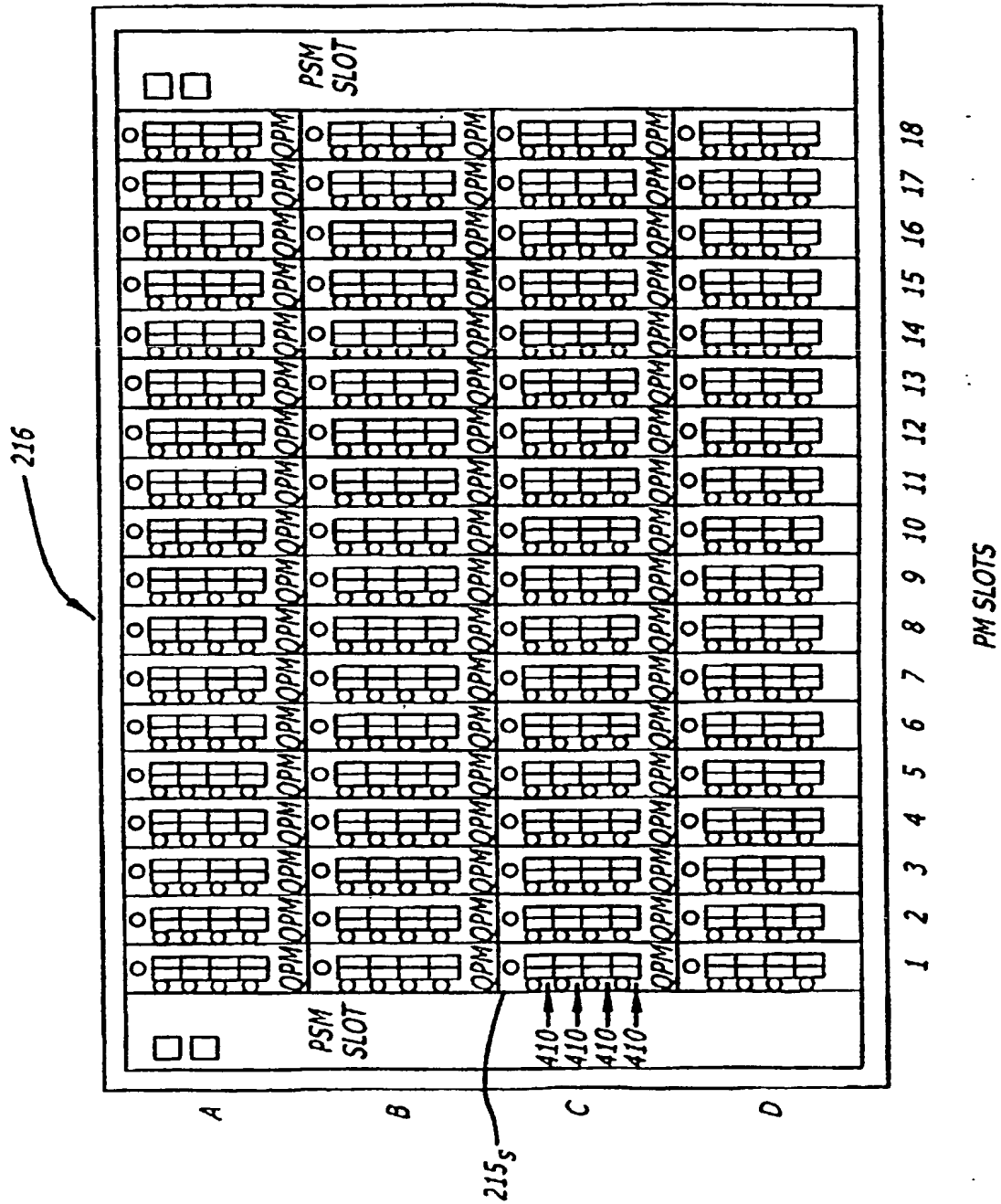


FIG. 5

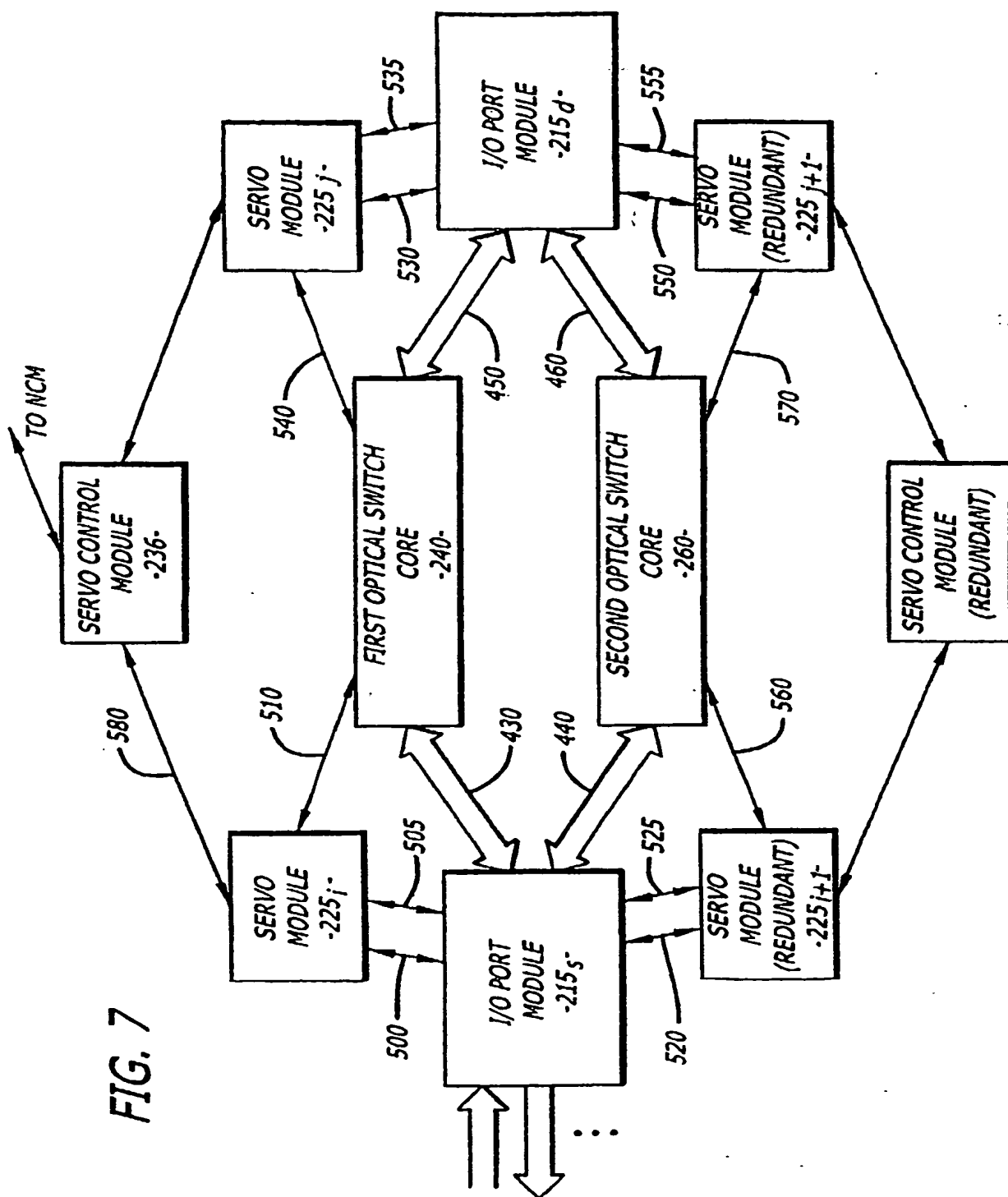


FIG. 8

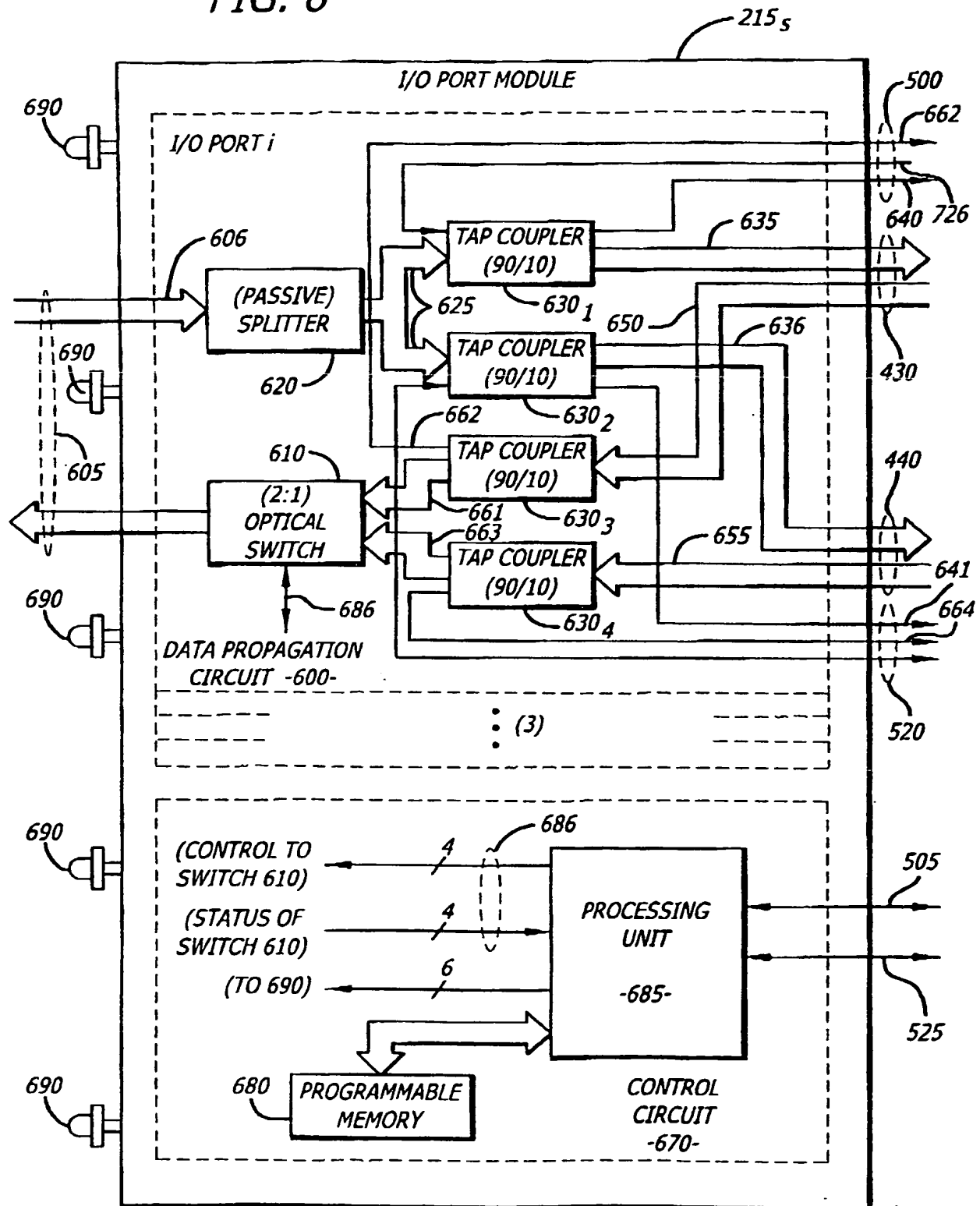
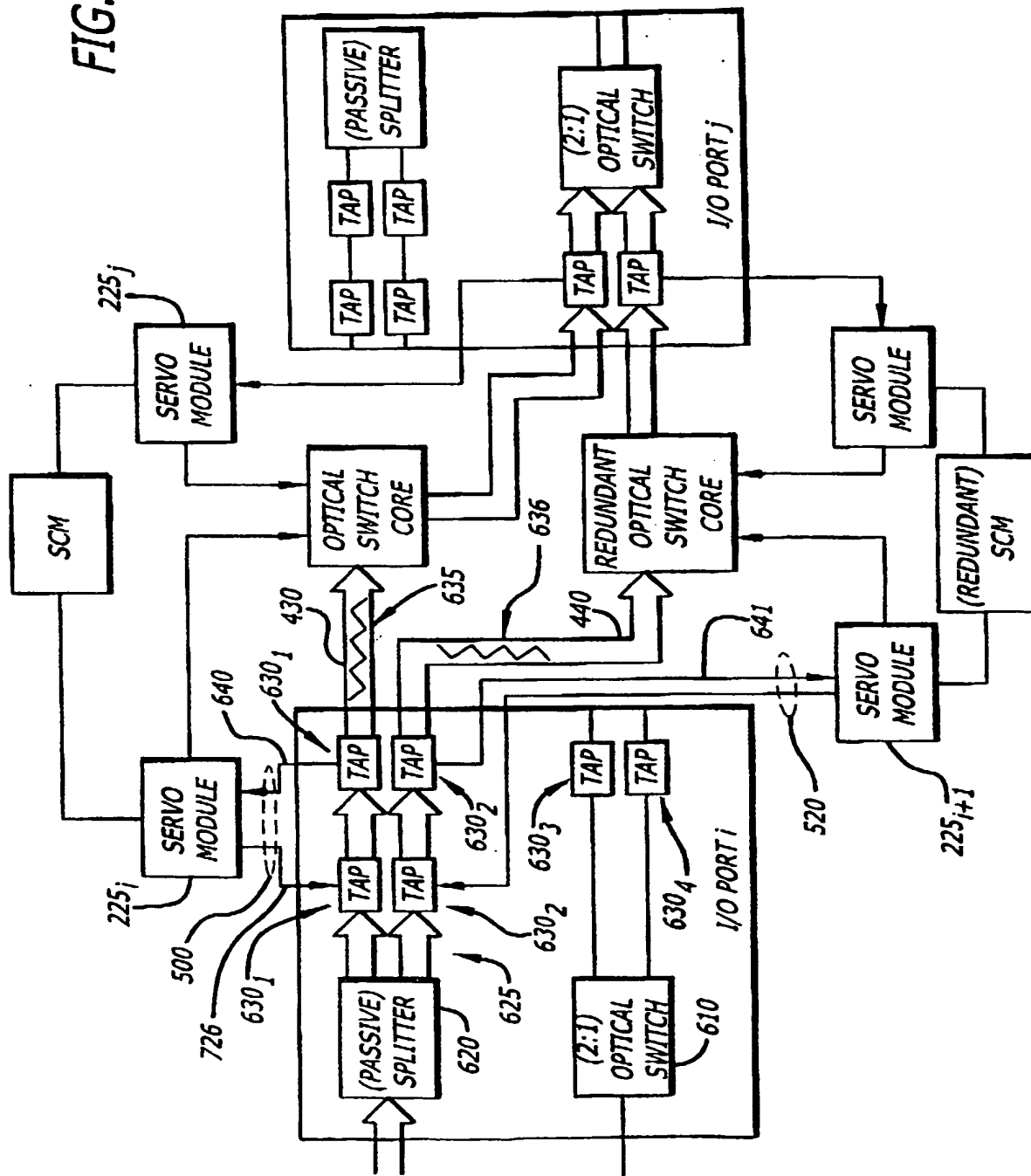




FIG. 9



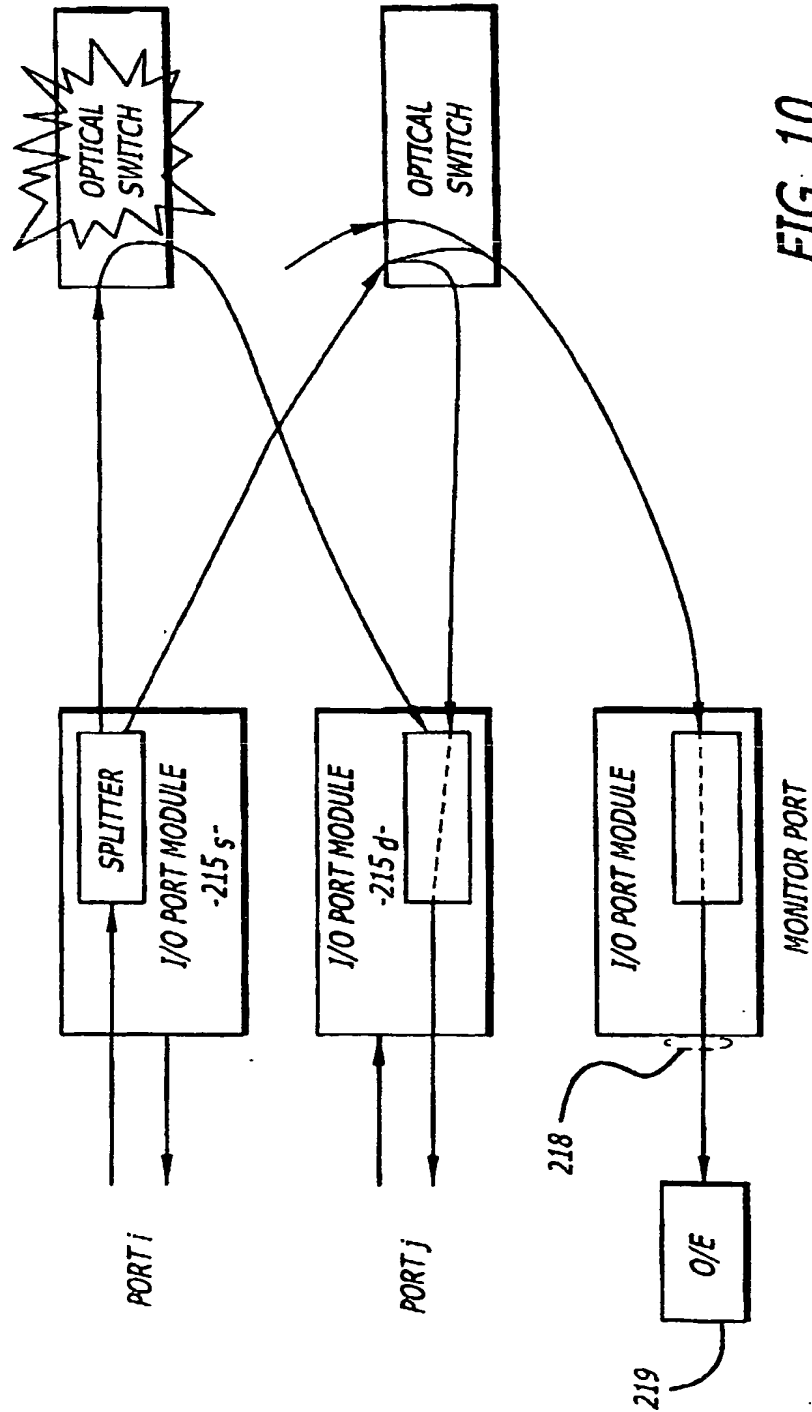


FIG. 10

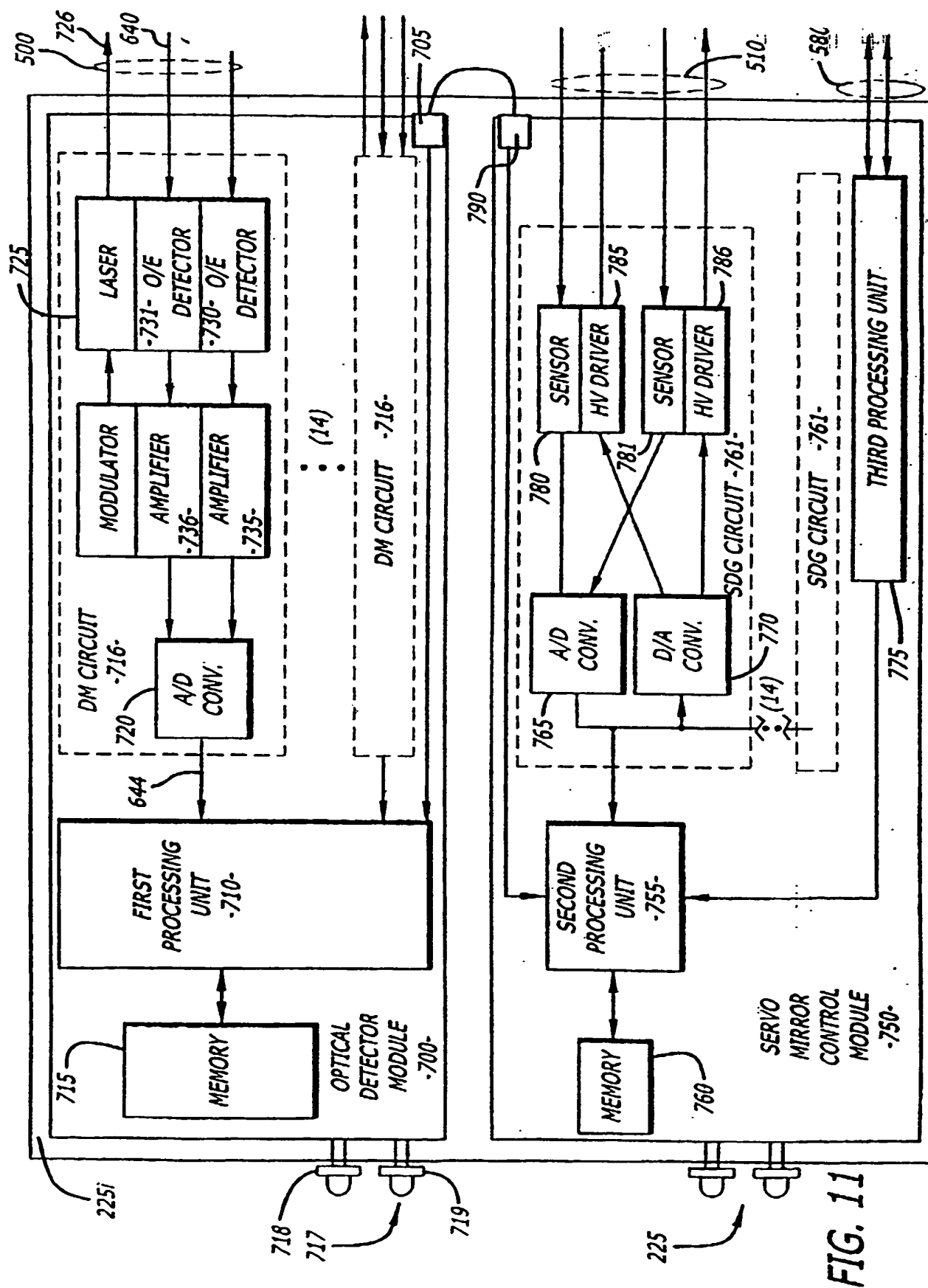
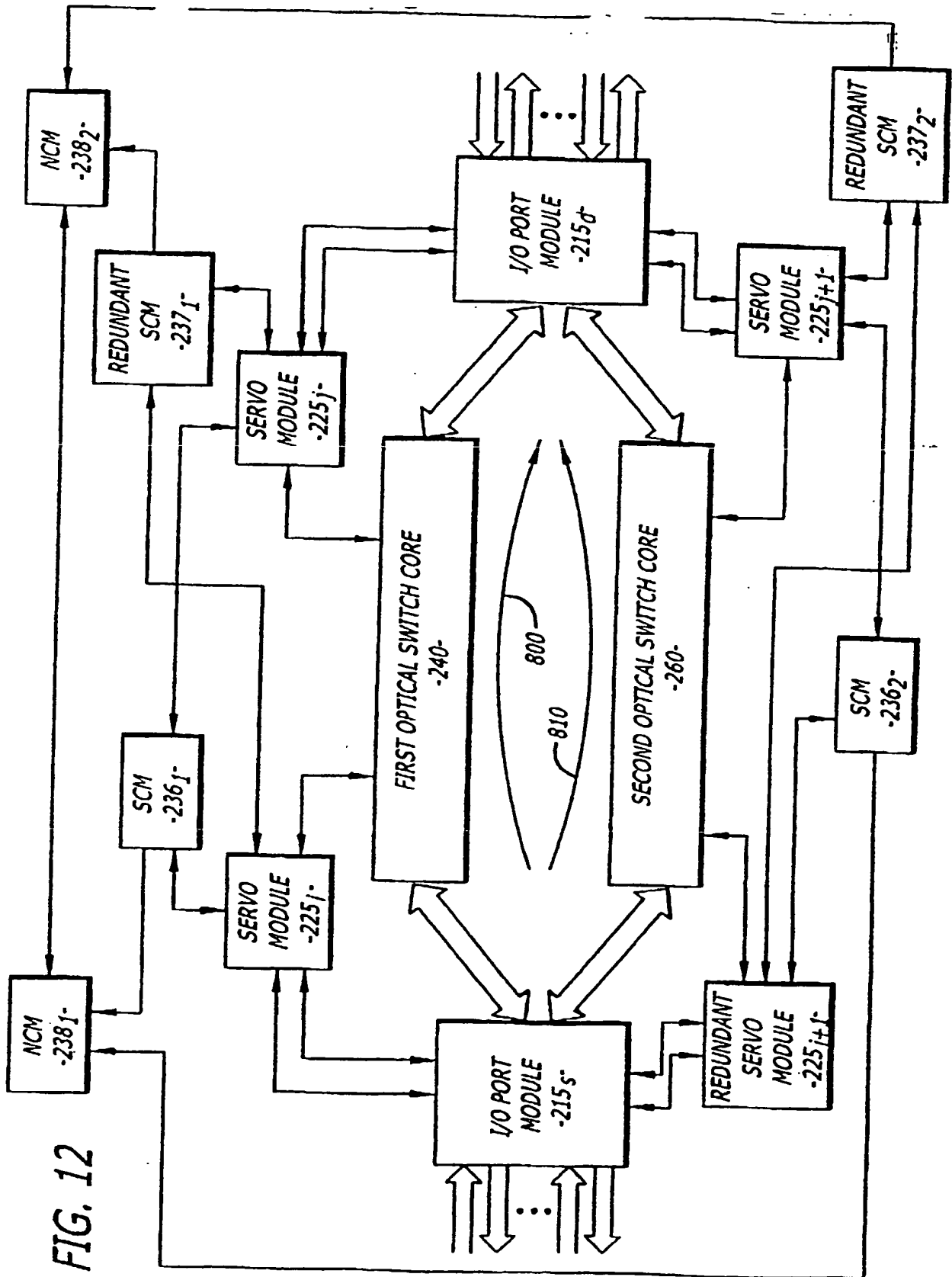


FIG. 11



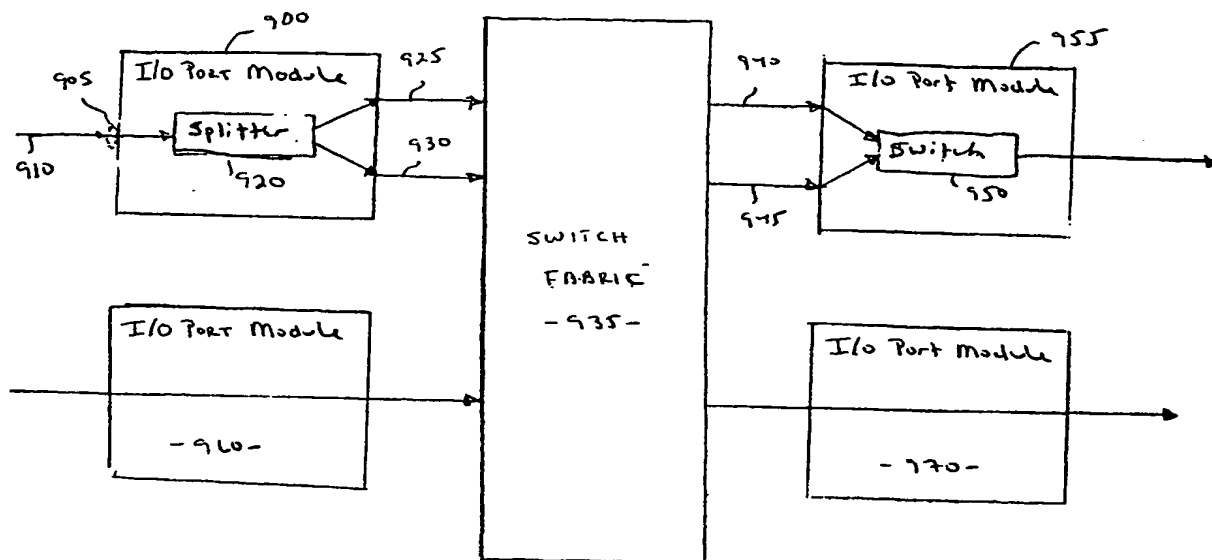


FIG 13

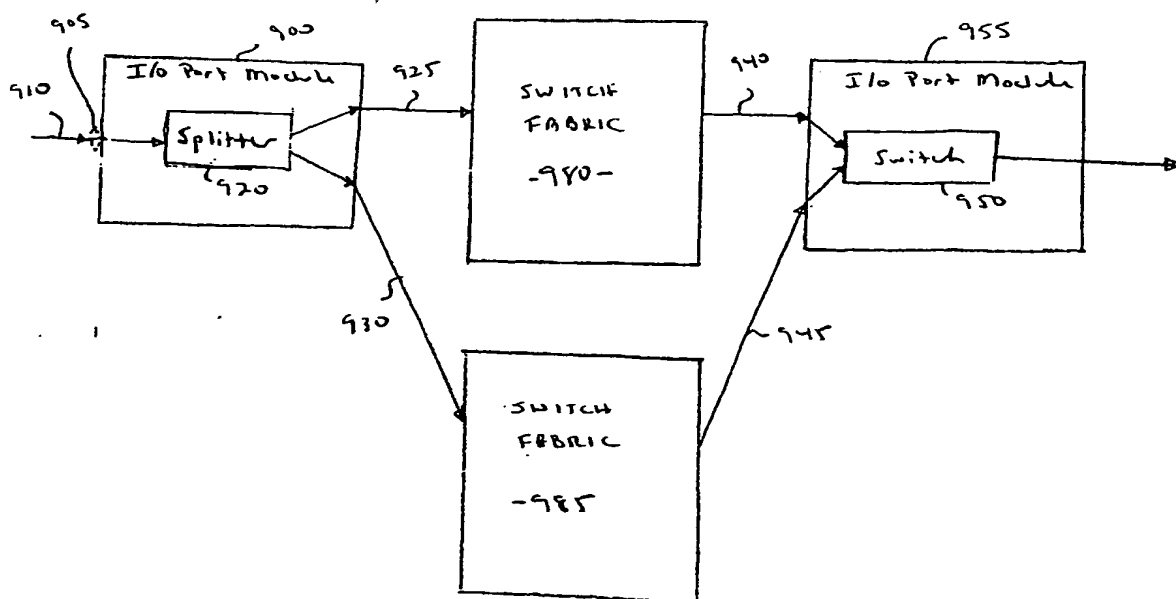


FIG 14

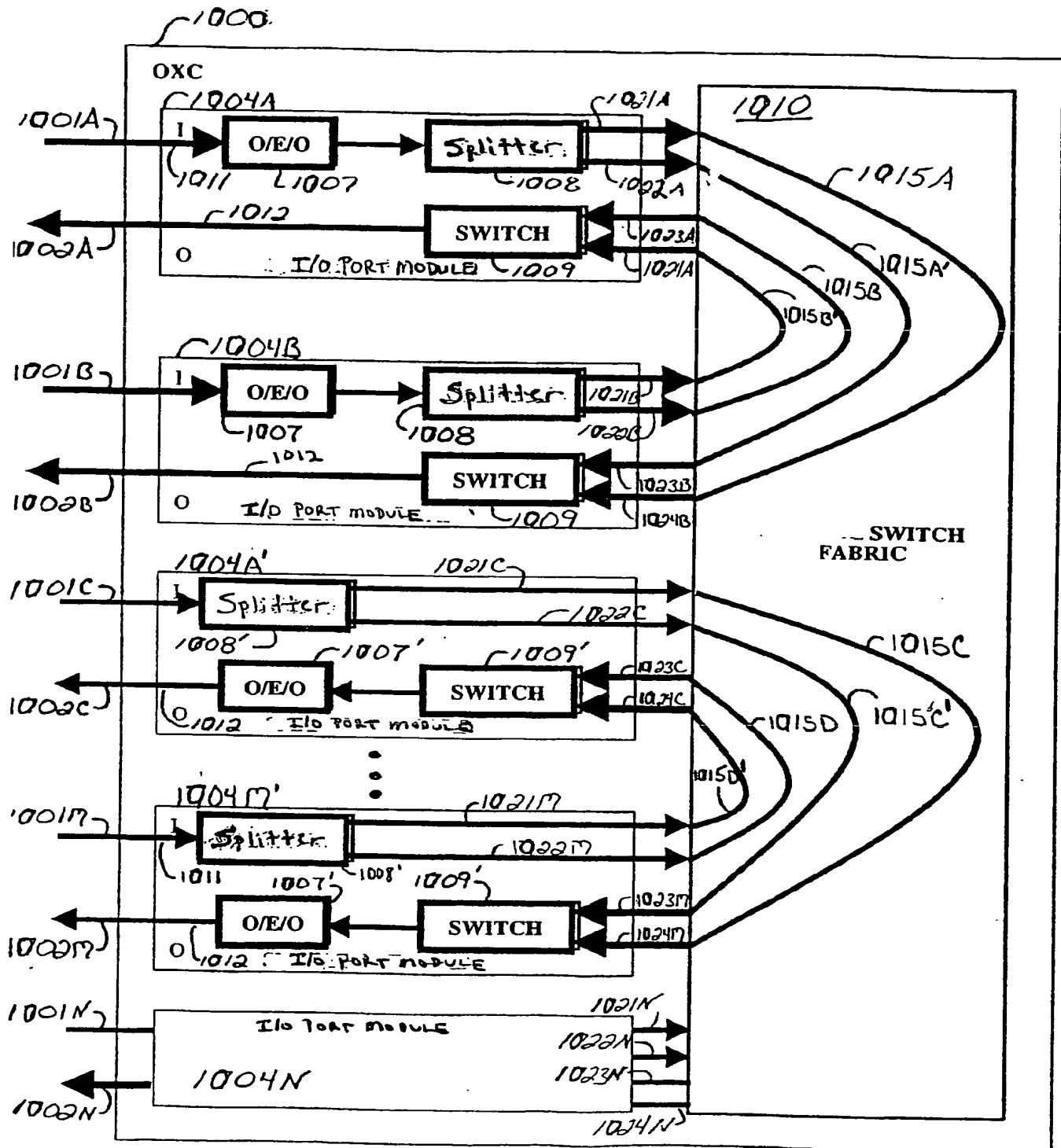


FIG. 15

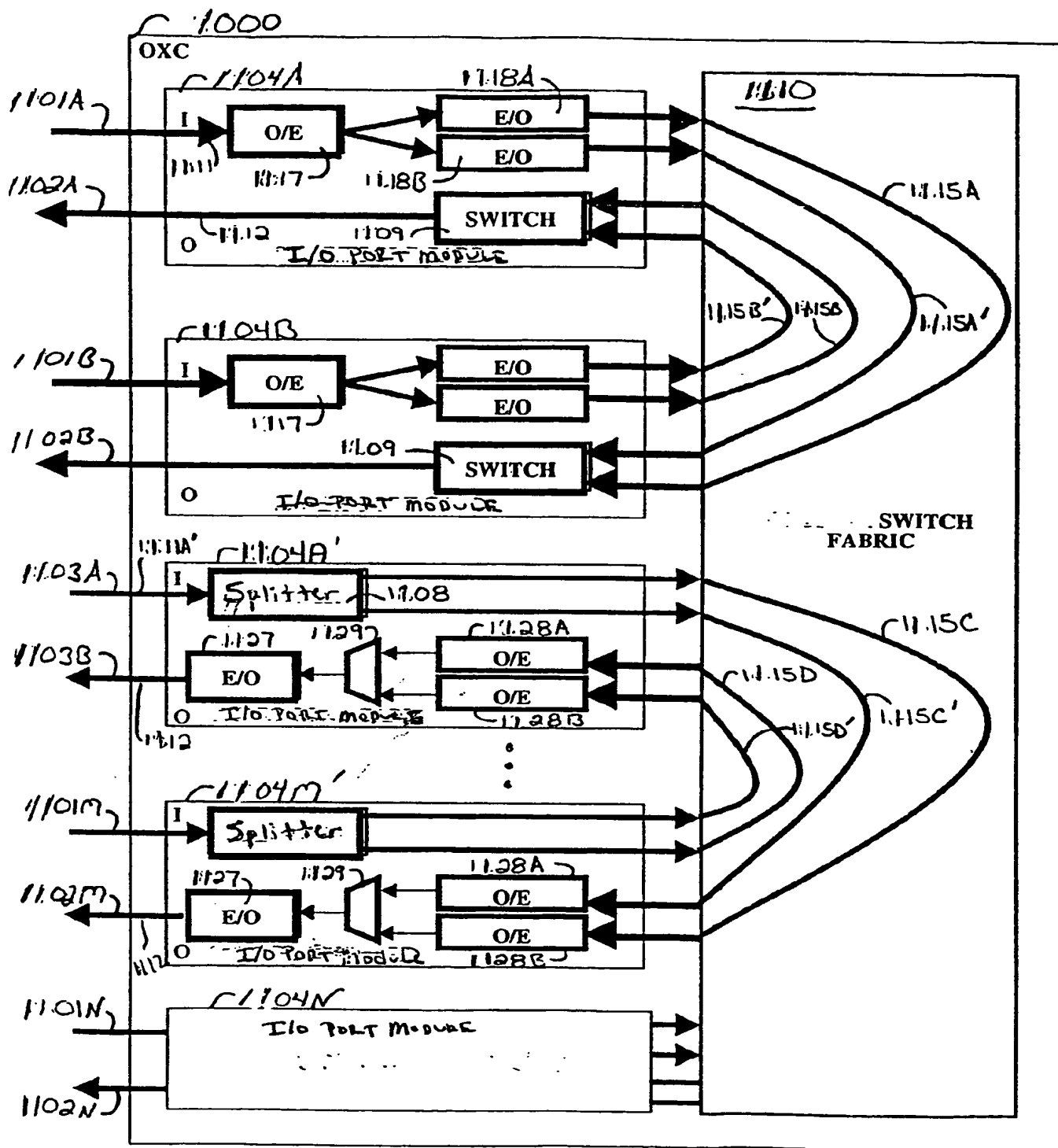


FIG. 16

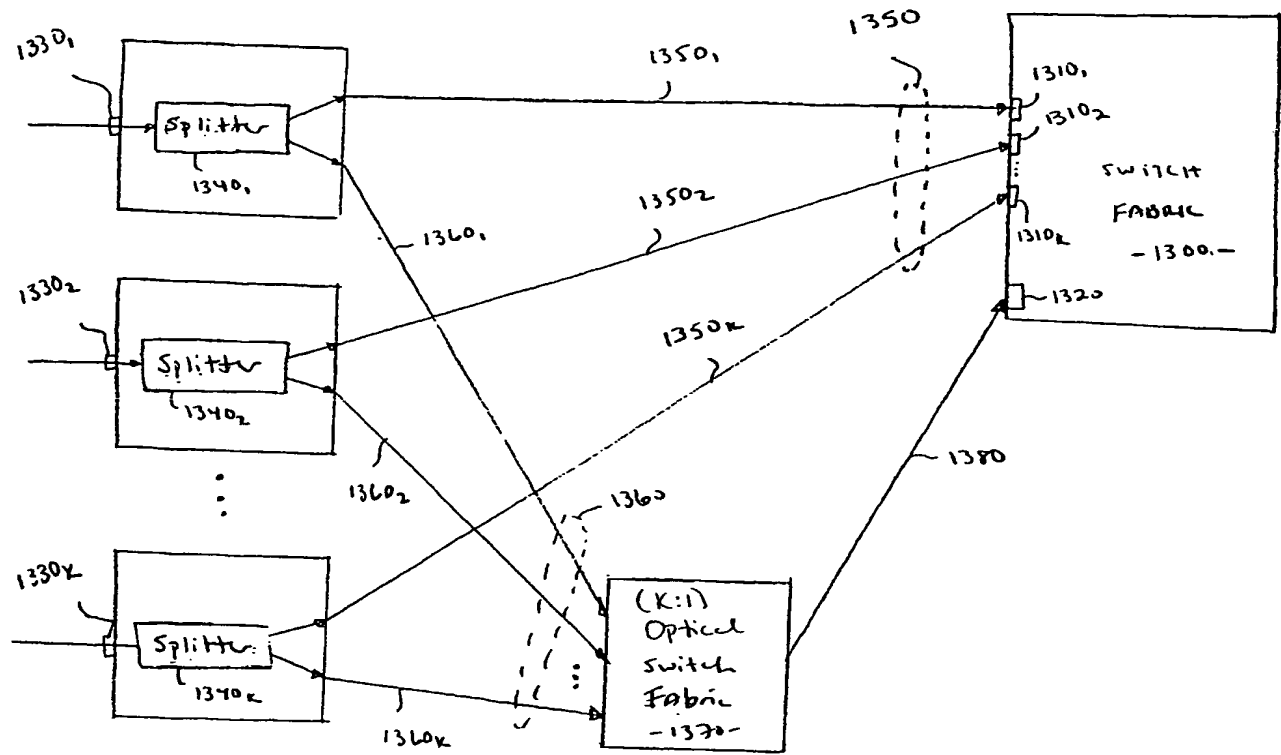


FIG. 17



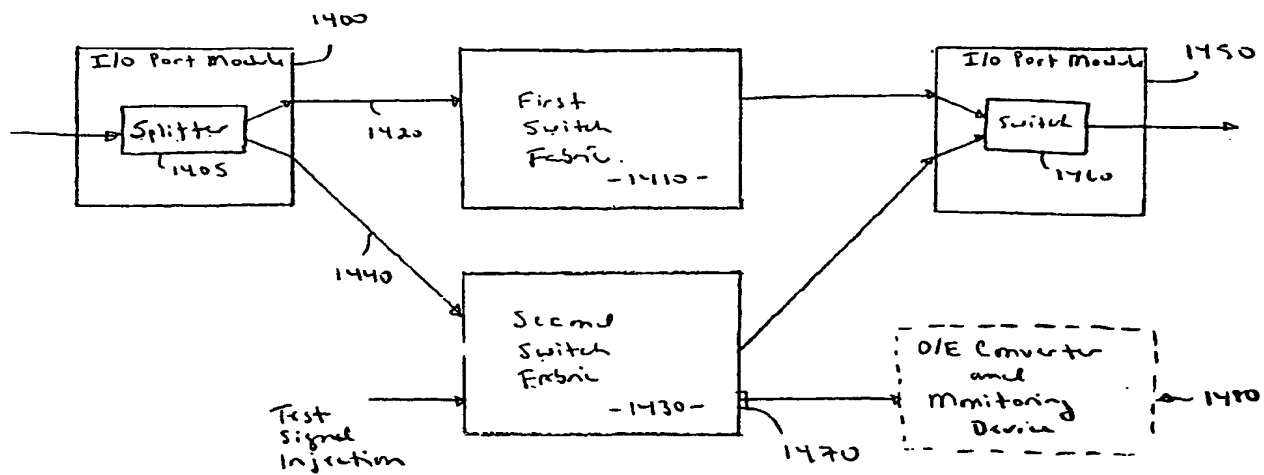


FIG. 18

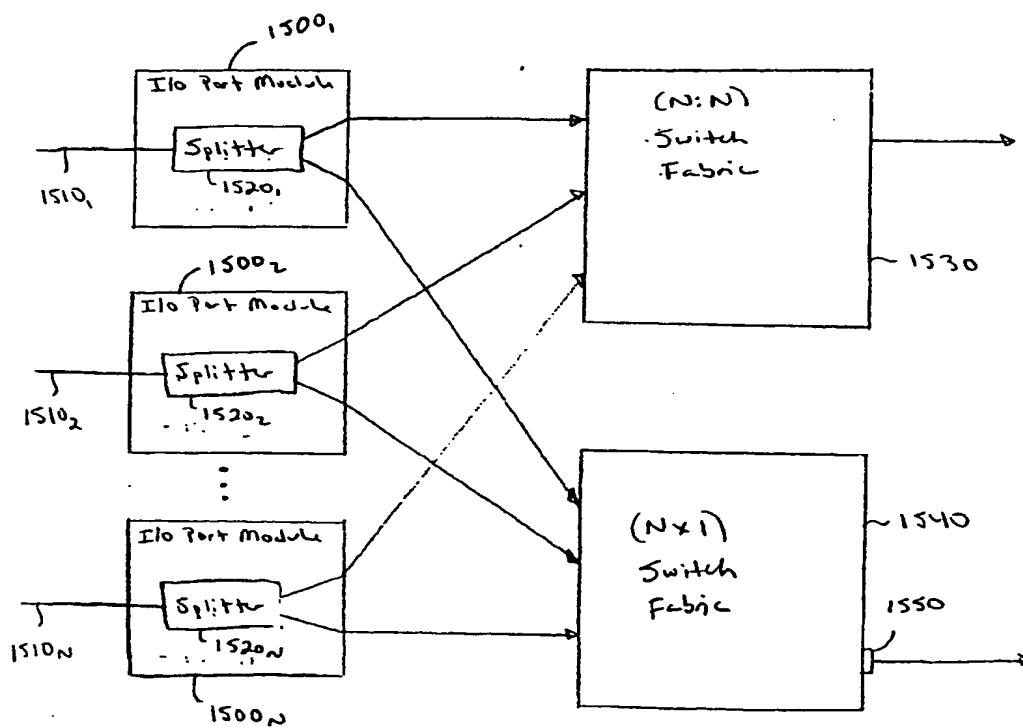


FIG. 19

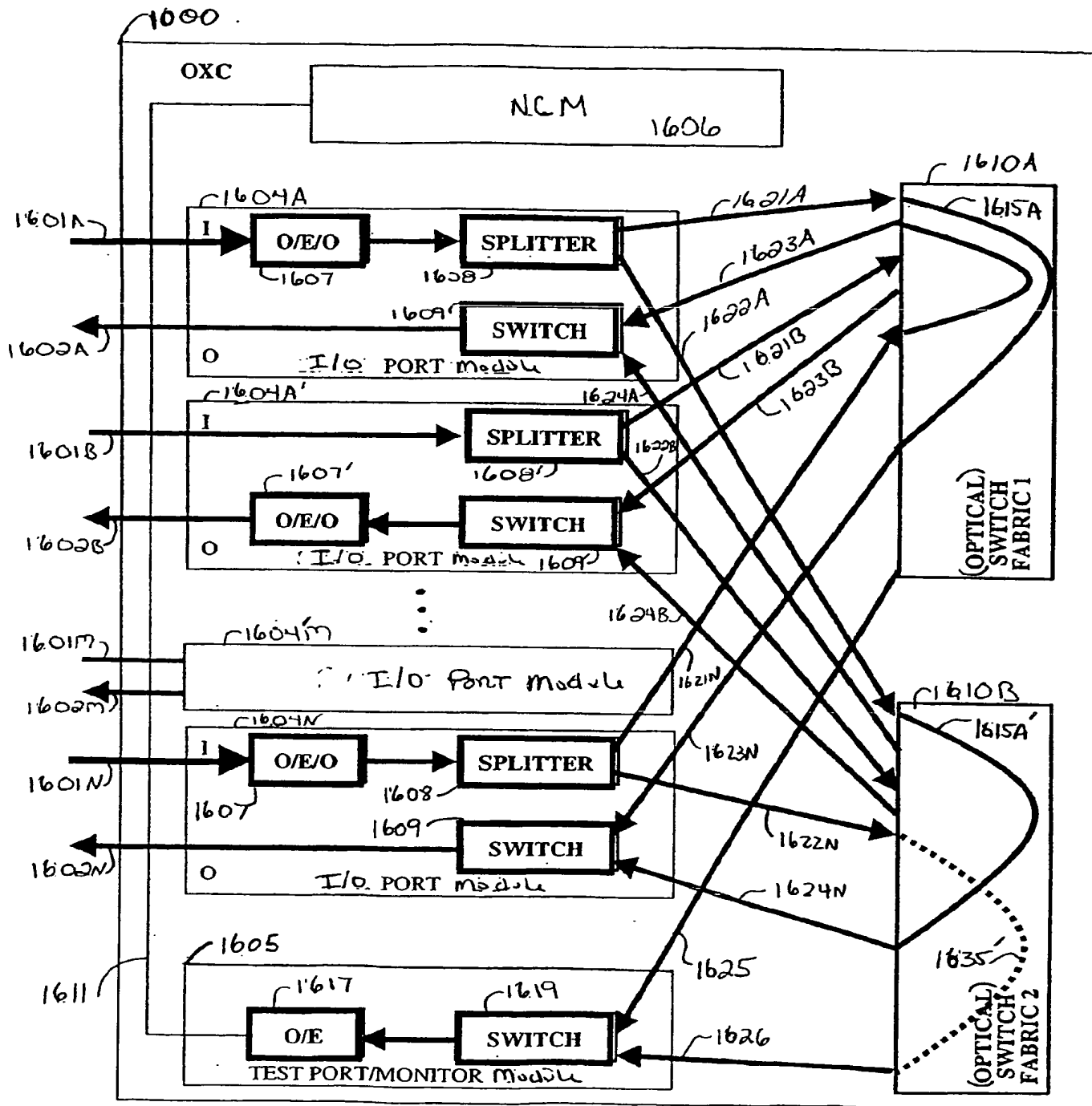


FIG. 20A

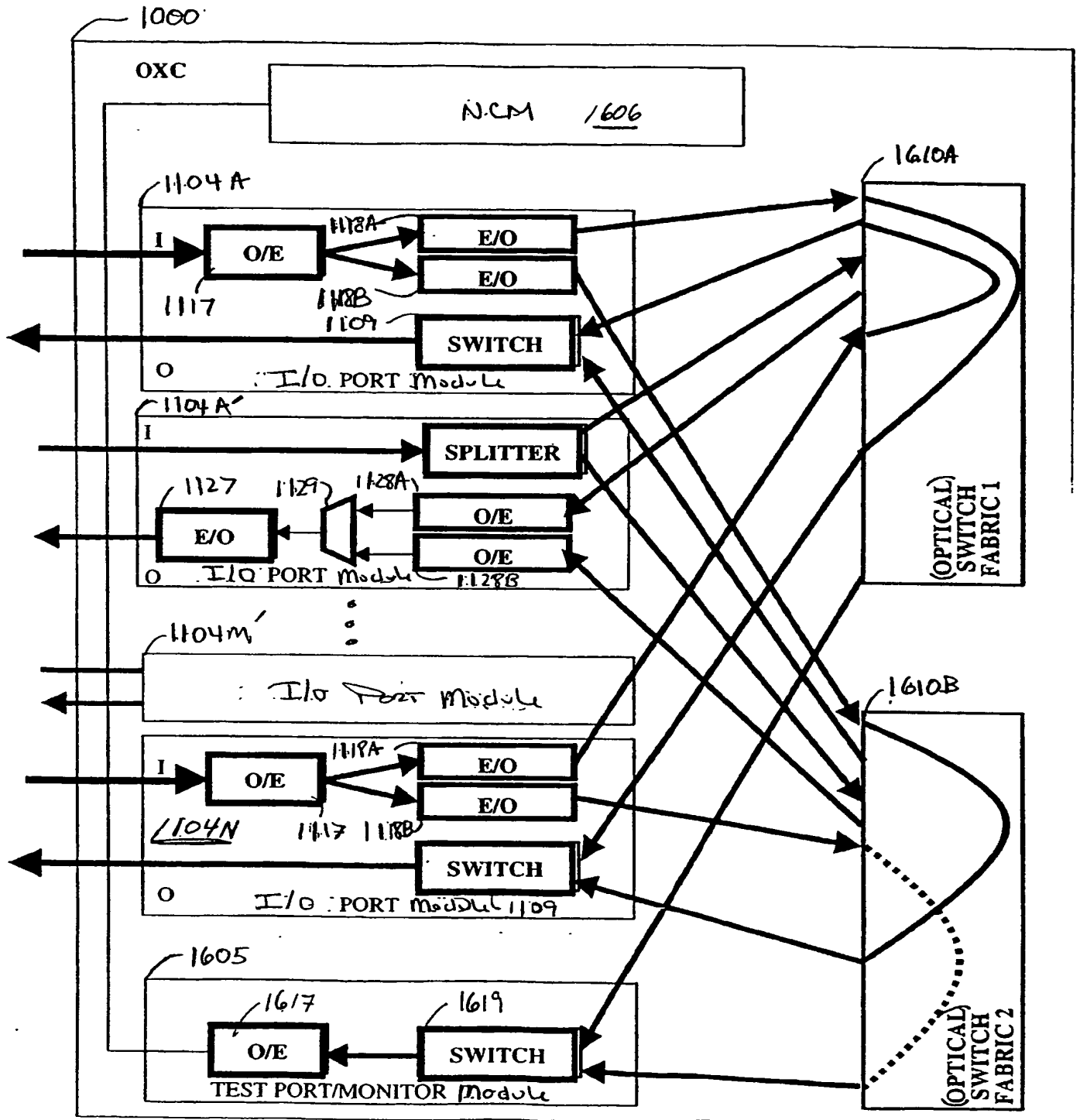


FIG. 20B

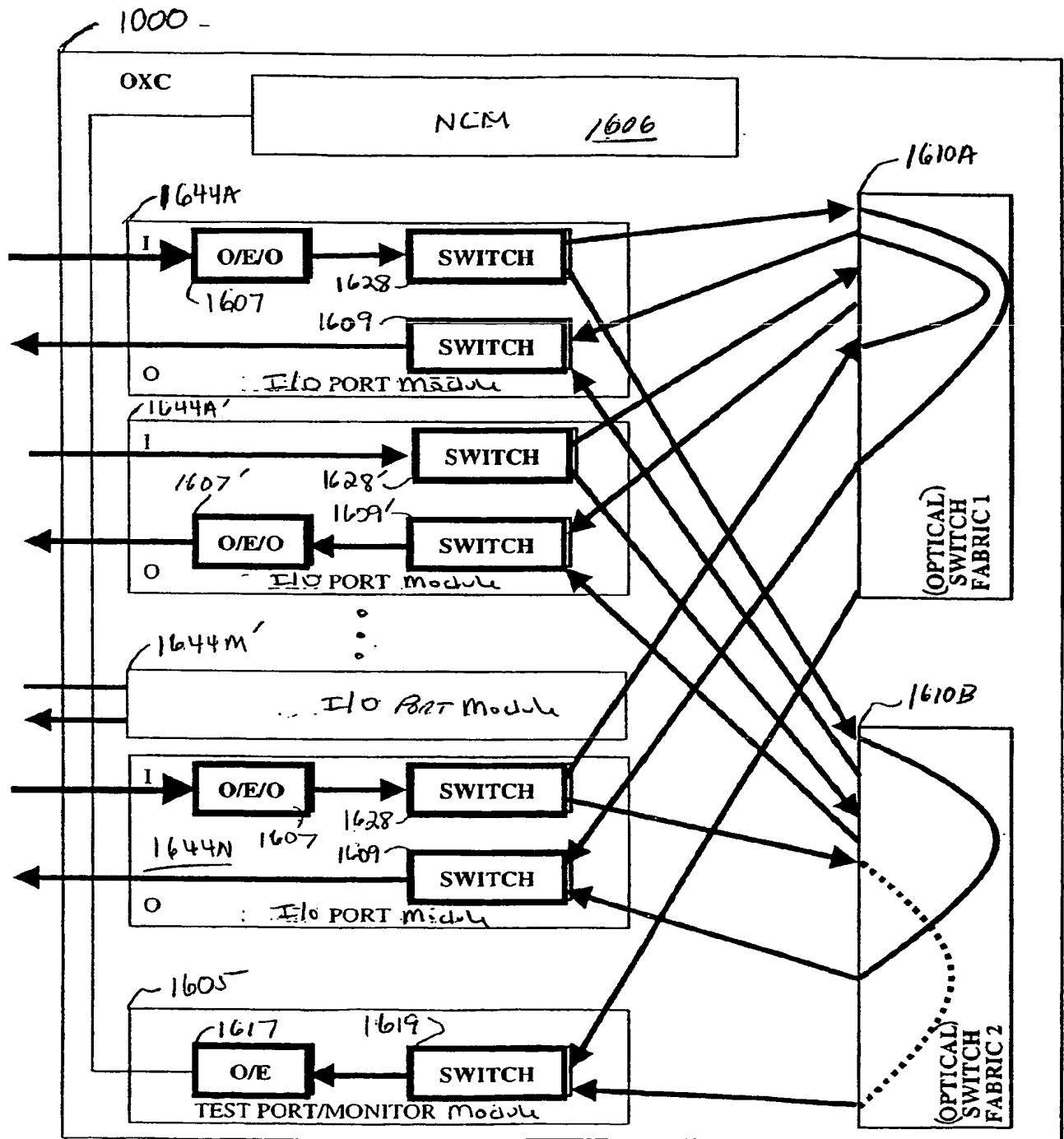


FIG. 20C

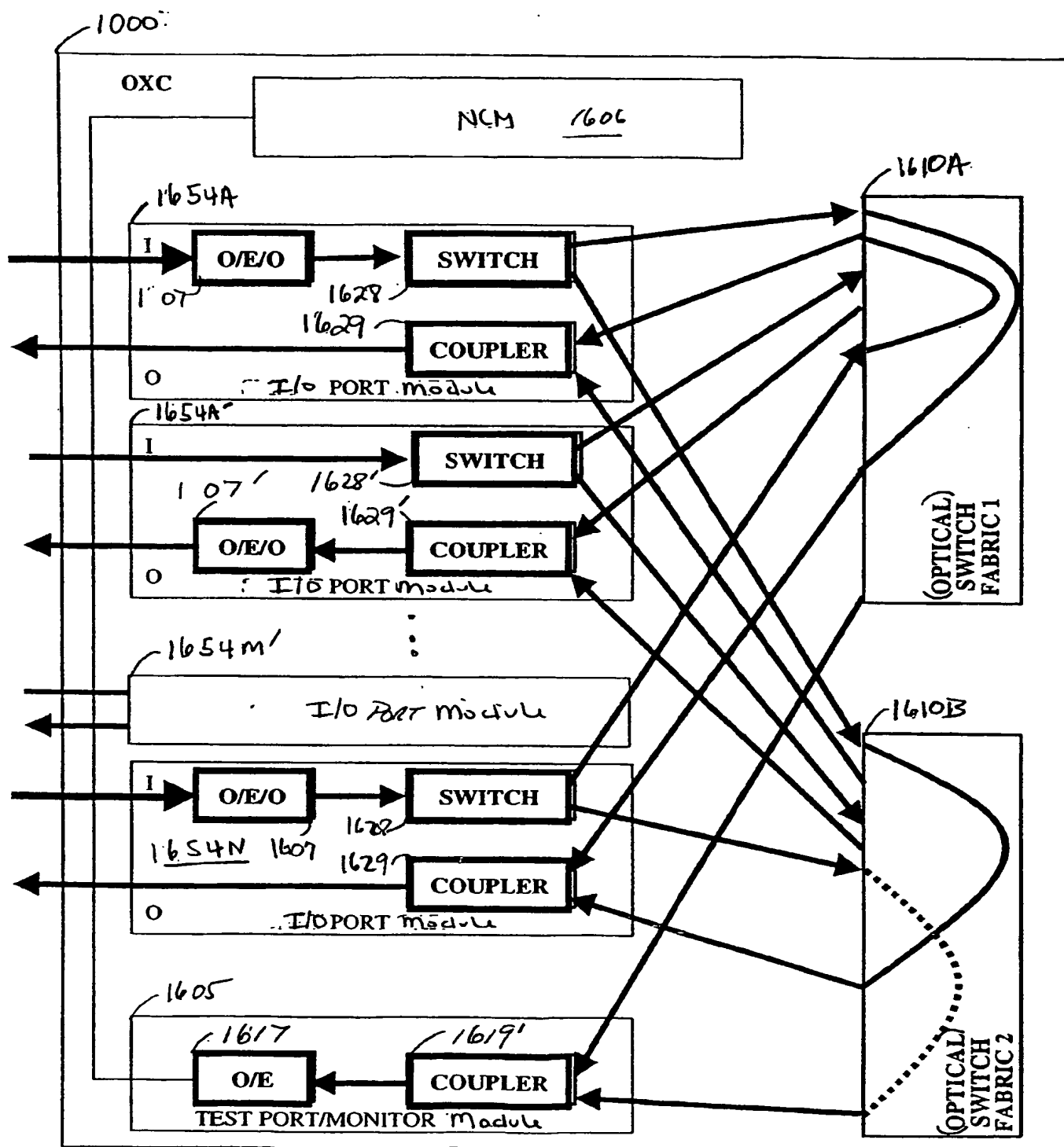


FIG. 20D

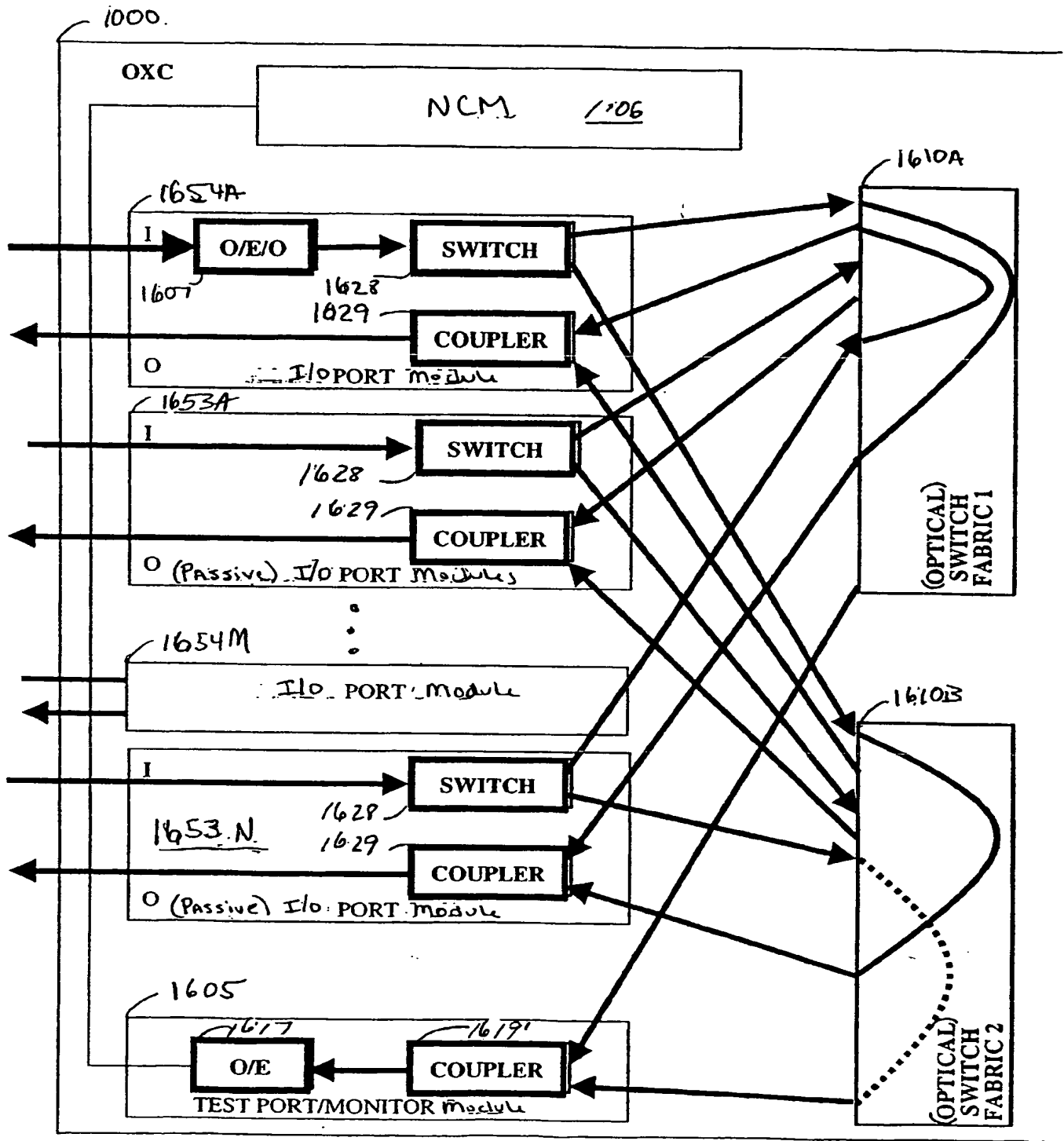


FIG. 20E

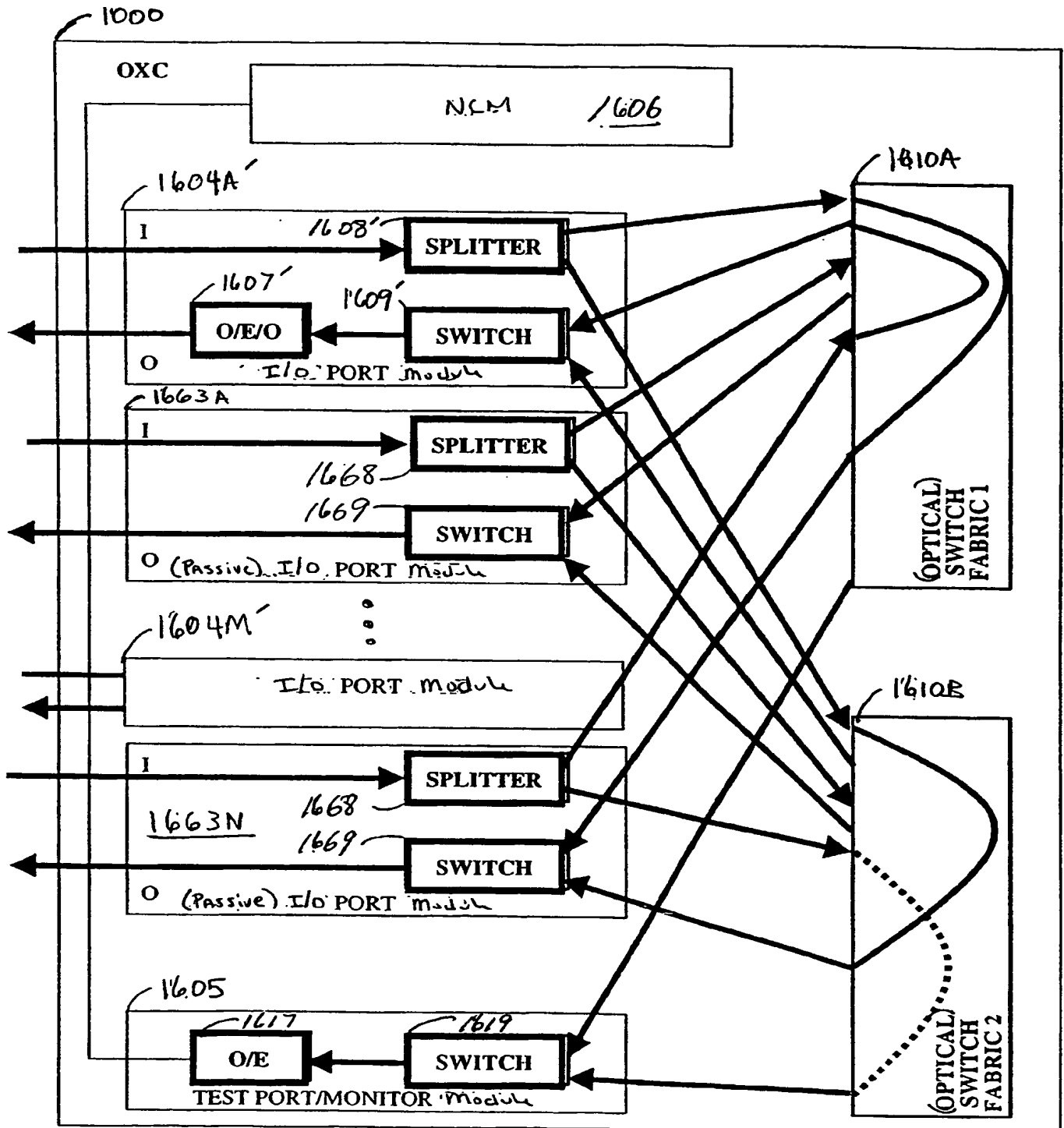


FIG. 20F

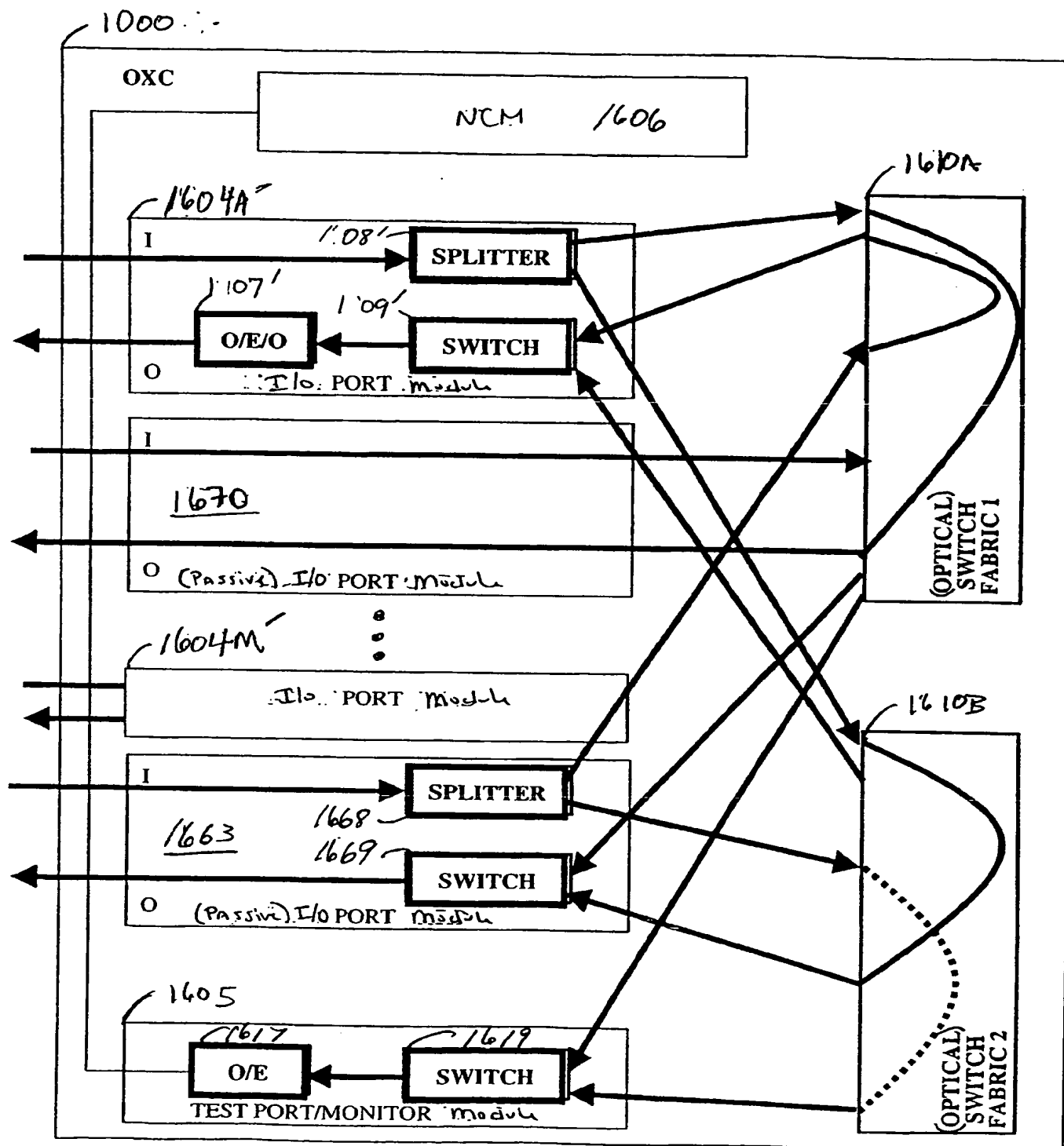


FIG. 206



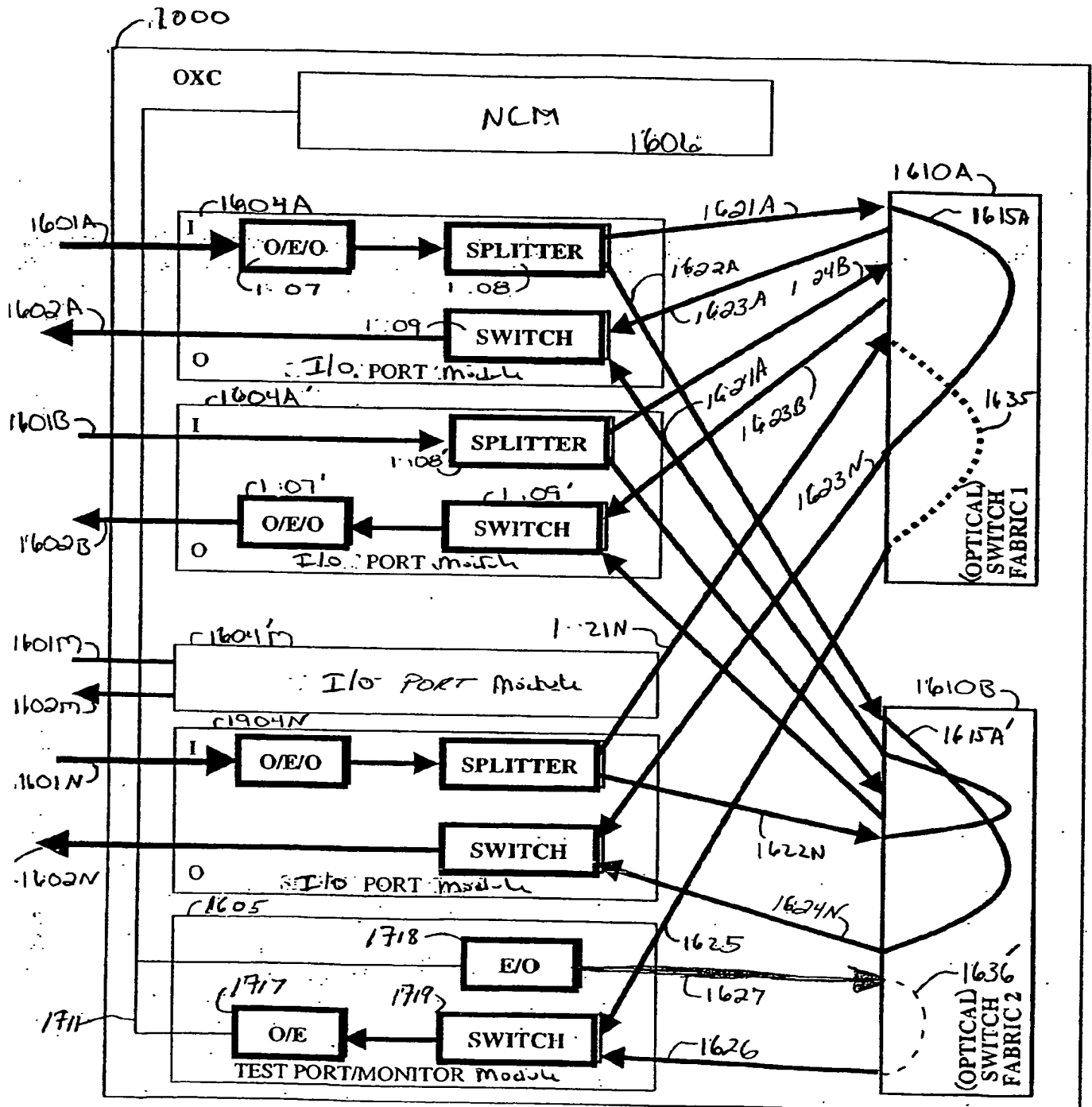


FIG. 21

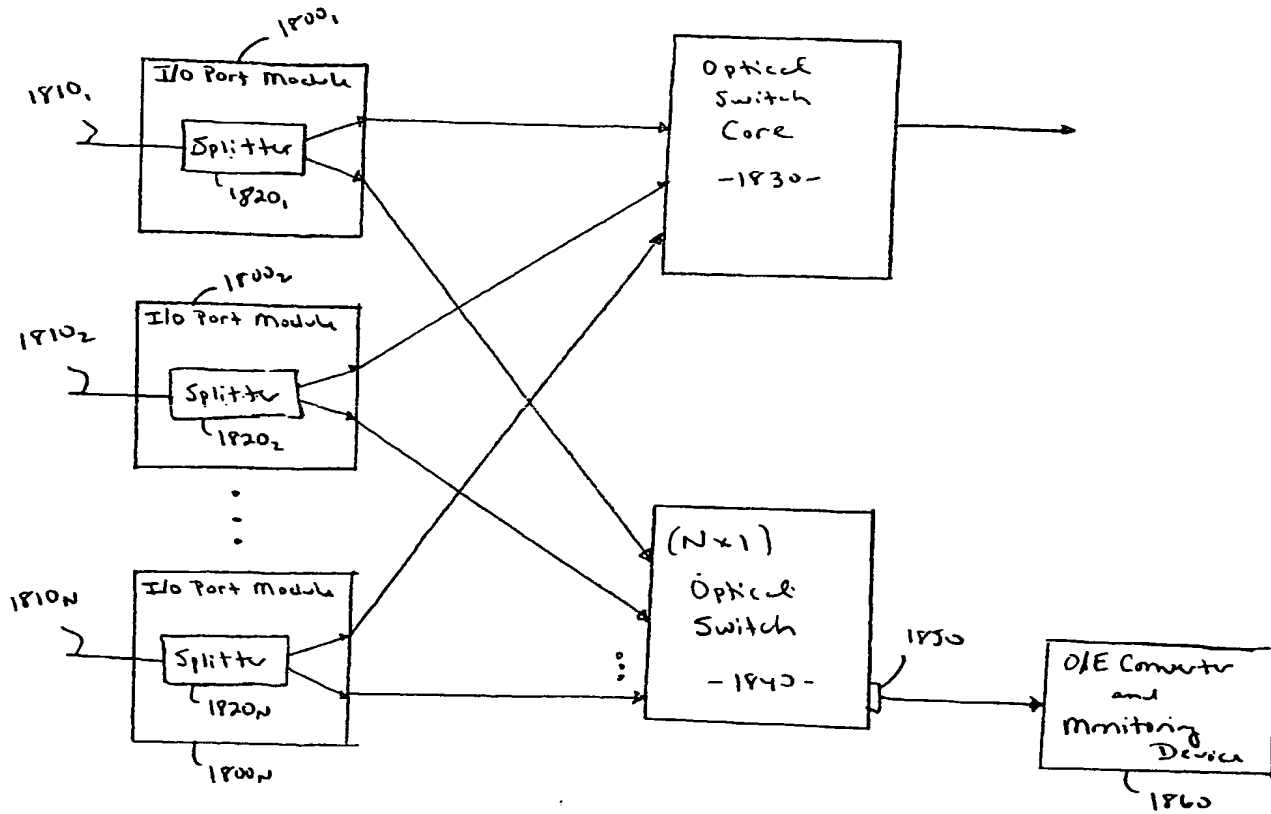


FIG. 22

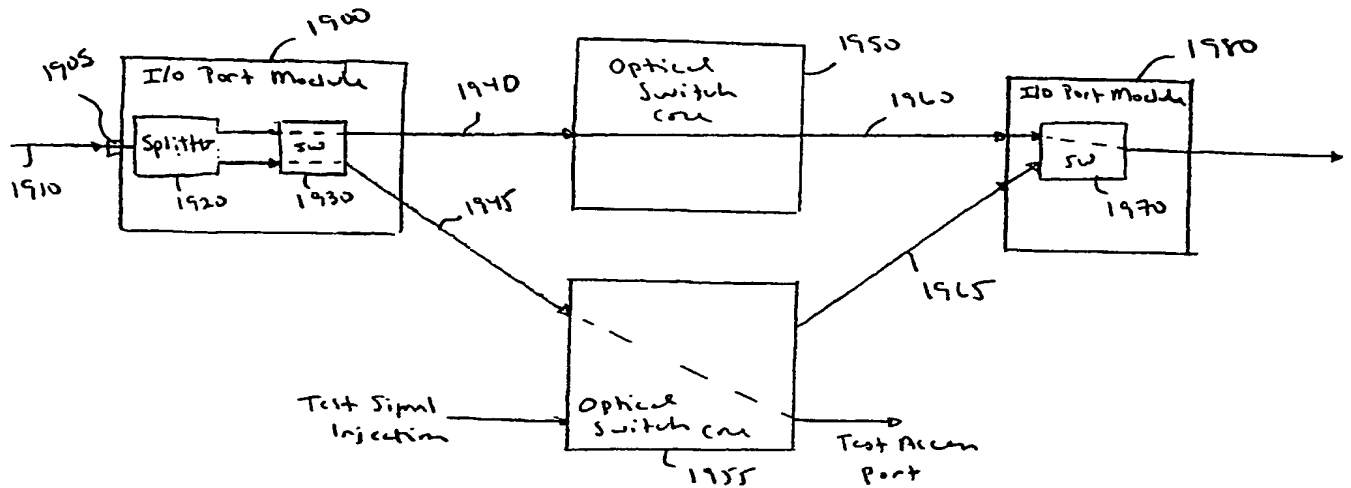


FIG. 23

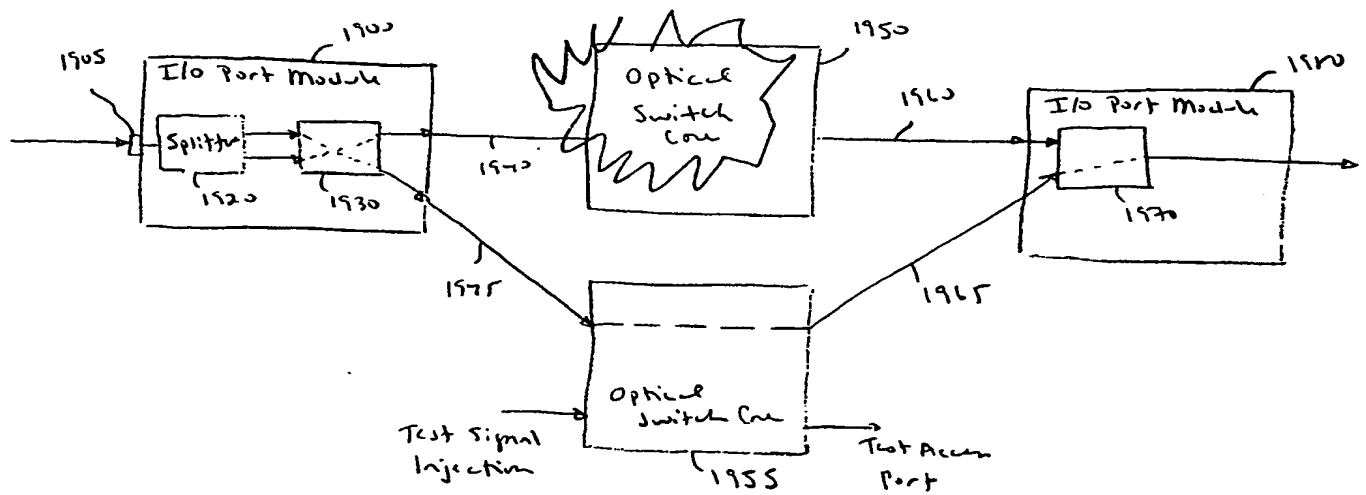


FIG. 24

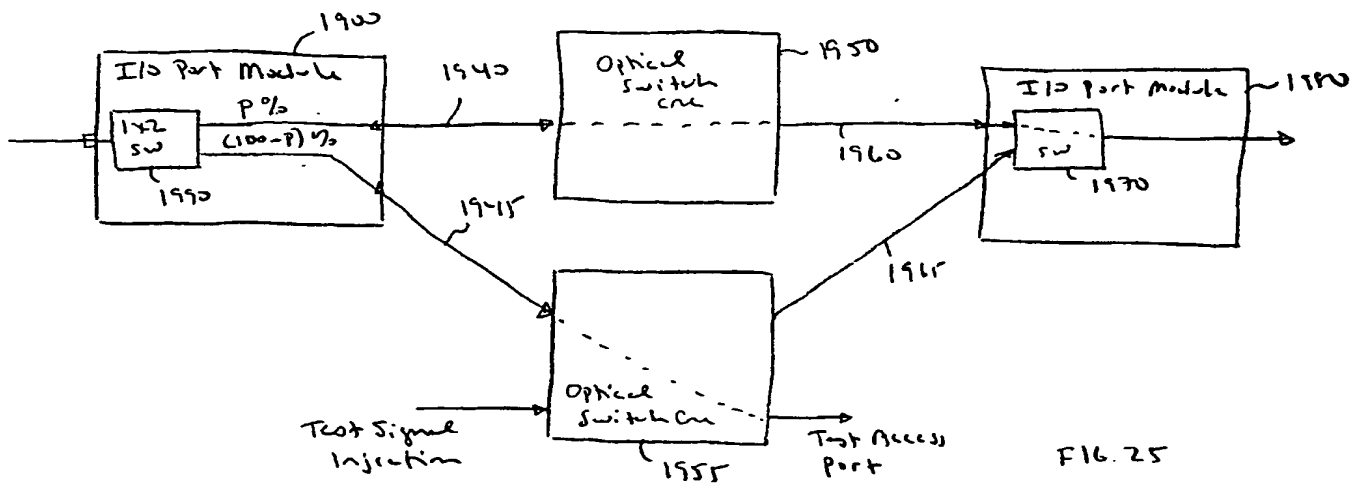


FIG. 25

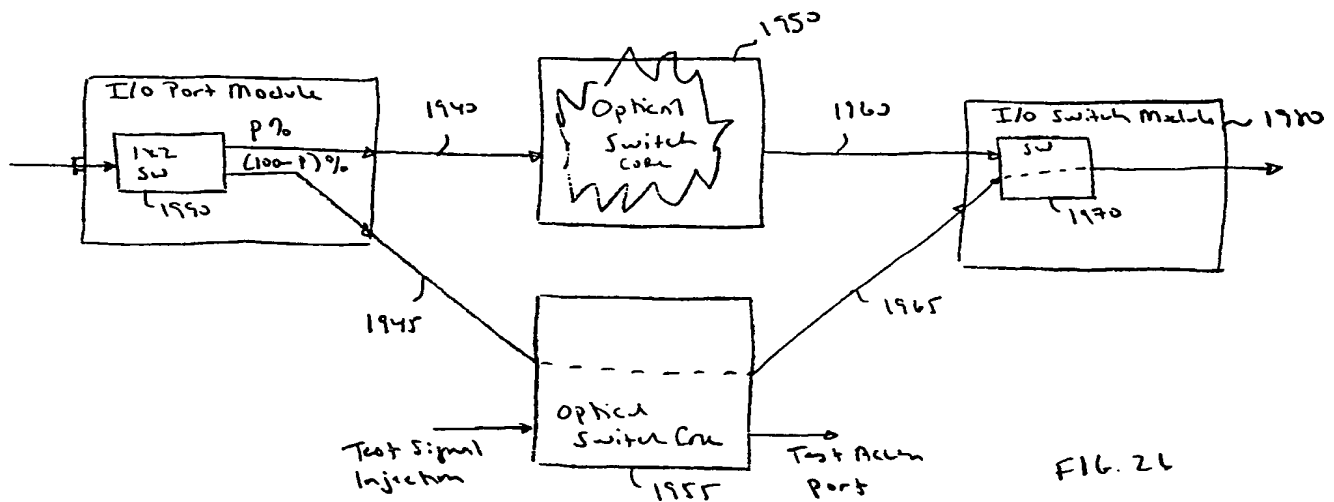


FIG. 26

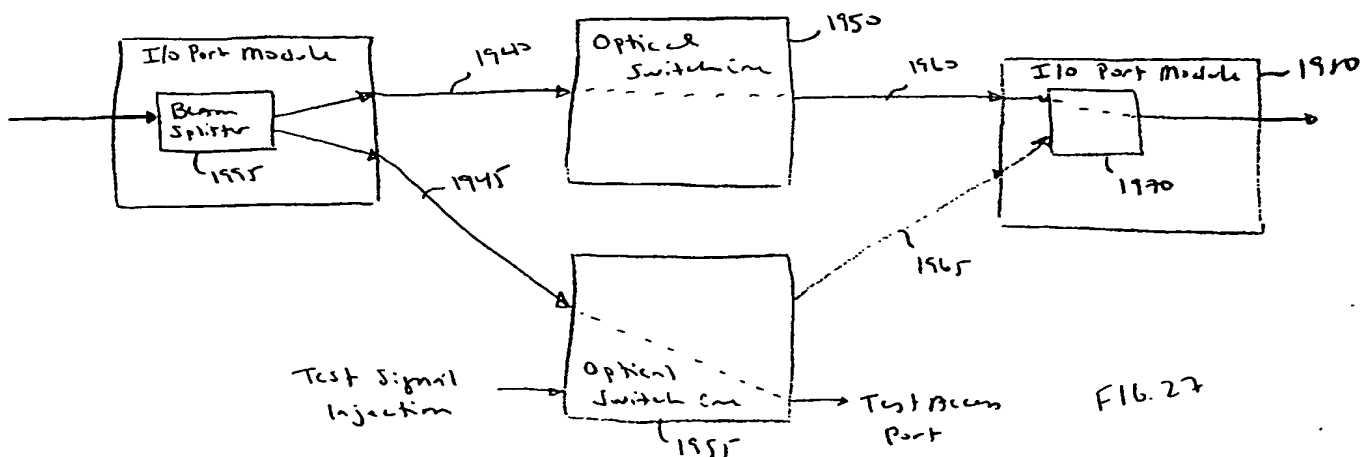


FIG. 27

(19) World Intellectual Property Organization  
International Bureau



(43) International Publication Date  
10 May 2001 (10.05.2001)

(10) International Publication Number  
**PCT**  
**WO 01/33897 A3**

(51) International Patent Classification<sup>7</sup>: **H04Q 11/00**

(21) International Application Number: **PCT/US00/30494**

(22) International Filing Date:  
2 November 2000 (02.11.2000)

(25) Filing Language: **English**

(26) Publication Language: **English**

(30) Priority Data:  
60/162,936 2 November 1999 (02.11.1999) US  
60/170,094 10 December 1999 (10.12.1999) US  
60/170,095 10 December 1999 (10.12.1999) US  
60/170,093 10 December 1999 (10.12.1999) US  
60/170,092 10 December 1999 (10.12.1999) US  
60/186,108 1 March 2000 (01.03.2000) US  
60/200,425 28 April 2000 (28.04.2000) US  
09/704,444 1 November 2000 (01.11.2000) US

(71) Applicant: **XROS, INC.** [US/US]; 2305 Mission College Boulevard, Santa Clara, CA 95054 (US).

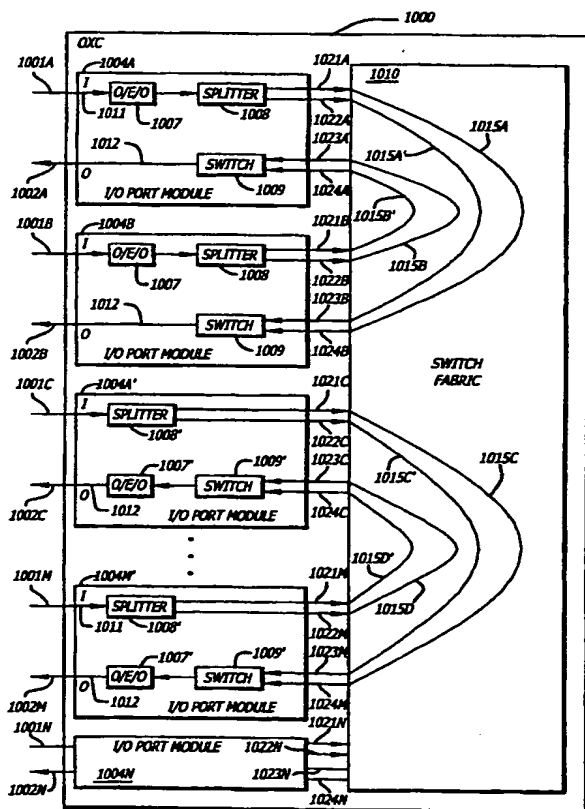
(72) Inventors: **RAMASWAMI, Rajiv**; 758 Carlisle Way, Sunnyvale, CA 94087 (US). **CLARK, Steven**; 922 Matadero Avenue, Palo Alto, CA 94306 (US). **WARD, Robert, R.**; 803 Selkirk Place, Sunnyvale, CA 94087 (US).

(74) Agents: **SCHAAL, William, W.** et al.; Blakely, Sokoloff, Taylor & Zafman, 7th floor, 12400 Wilshire Blvd., Los Angeles, CA 90025-1026 (US).

(81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW.

[Continued on next page]

(54) Title: **AN OPTICAL CROSS-CONNECT SWITCHING SYSTEM WITH BRIDGING, TEST ACCESS AND REDUNDANCY**



(57) Abstract: In one embodiment, a scalable cross-connect switching system and its corresponding method perform a bridging operation by splitting the incoming light signal into at least a first bridged light signal and a second bridged light signal. The first bridged light signal has a power level equal to or substantially greater than a power level of the second bridged light signal. The disproportionate power levels provide low-loss bridging. Light signals based on these bridged light signals are routed through multiple switch fabrics which provide redundancy in case of failure by switching within the switch fabric. To detect failures, a test access port is configured for monitoring multiple optical paths.

WO 01/33897 A3



(84) **Designated States (regional):** ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

(88) **Date of publication of the international search report:**  
22 November 2001

*For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

**Published:**

— with international search report

# INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 00/30494

## A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 H04Q11/00

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 H04Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 938 244 A (FUJITSU LTD) 25 August 1999 (1999-08-25)	7-9, 14, 15, 17-20, 22, 27, 29, 31, 32 1, 33
A	abstract paragraphs '0003!-'0012! figure 6A column 29, line 6-9	
A	WO 99 40738 A (TOL JOHANNES JACOBUS GERARDUS ;KONINKL KPN NV (NL)) 12 August 1999 (1999-08-12) abstract	4, 11, 33
A	EP 0 857 000 A (NIPPON ELECTRIC CO) 5 August 1998 (1998-08-05) abstract	1-38
	-/--	

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

### \* Special categories of cited documents :

\*A\* document defining the general state of the art which is not considered to be of particular relevance

\*E\* earlier document but published on or after the international filing date

\*L\* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

\*O\* document referring to an oral disclosure, use, exhibition or other means

\*P\* document published prior to the international filing date but later than the priority date claimed

\*T\* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

\*X\* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

\*Y\* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

\*G\* document member of the same patent family

Date of the actual completion of the international search

3 August 2001

Date of mailing of the international search report

10/08/2001

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2  
NL - 2280 HV Rijswijk  
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,  
Fax: (+31-70) 340-3016

Authorized officer

Dhondt, E

# INTERNATIONAL SEARCH REPORT

In ational Application No

PCT/US 00/30494

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 849 906 A (FUJITSU LTD) 24 June 1998 (1998-06-24) column 61, line 56 -column 62, line 3 -----	7
A	EP 0 674 457 A (FUJITSU LTD) 27 September 1995 (1995-09-27) figures 48,49 -----	16,28,30



# INTERNATIONAL SEARCH REPORT

Information on patent family members

In. tional Application No

PCT/US 00/30494

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
EP 0938244	A	25-08-1999	JP 11239100 A	31-08-1999
WO 9940738	A	12-08-1999	NL 1008206 C	06-08-1999
			AU 2718299 A	23-08-1999
			EP 1053647 A	22-11-2000
EP 0857000	A	05-08-1998	JP 3006680 B	07-02-2000
			JP 10224828 A	21-08-1998
			US 6061156 A	09-05-2000
EP 0849906	A	24-06-1998	JP 10178418 A	30-06-1998
			CN 1185688 A	24-06-1998
			US 6118564 A	12-09-2000
EP 0674457	A	27-09-1995	JP 7307745 A	21-11-1995
			CA 2144837 A	18-09-1995
			US 5610913 A	11-03-1997

Form PCT/ISA/210 (patent family annex) (July 1992)



CORRECTED VERSION

(19) World Intellectual Property Organization  
International Bureau



(43) International Publication Date  
10 May 2001 (10.05.2001)

PCT

(10) International Publication Number  
**WO 01/33897 A3**

(51) International Patent Classification<sup>7</sup>: **H04Q 11/00**

60/200,425 28 April 2000 (28.04.2000) US  
09/704,444 1 November 2000 (01.11.2000) US

(21) International Application Number: PCT/US00/30494

(22) International Filing Date:  
2 November 2000 (02.11.2000)

(71) Applicant: **XROS, INC.** [US/US]; 2305 Mission College  
Boulevard, Santa Clara, CA 95054 (US).

(25) Filing Language: English

(72) Inventors: **RAMASWAMI, Rajiv**; 758 Carlisle Way,  
Sunnyvale, CA 94087 (US). **CLARK, Steven**; 922  
Matadero Avenue, Palo Alto, CA 94306 (US). **WARD,  
Robert, R.**; 803 Selkirk Place, Sunnyvale, CA 94087  
(US).

(26) Publication Language: English

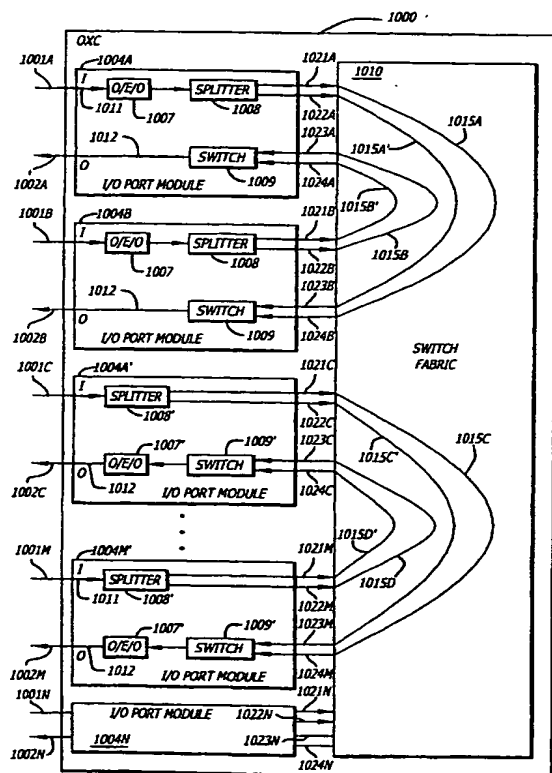
(30) Priority Data:  
60/162,936 2 November 1999 (02.11.1999) US  
60/170,094 10 December 1999 (10.12.1999) US  
60/170,095 10 December 1999 (10.12.1999) US  
60/170,093 10 December 1999 (10.12.1999) US  
60/170,092 10 December 1999 (10.12.1999) US  
60/186,108 1 March 2000 (01.03.2000) US

(74) Agents: **SCHAAL, William, W.** et al.; Blakely, Sokoloff,  
Taylor & Zafman, 7th floor, 12400 Wilshire Blvd., Los An-  
geles, CA 90025-1026 (US).

(81) Designated States (*national*): AE, AG, AL, AM, AT, AU,  
AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ,

[Continued on next page]

(54) Title: AN OPTICAL CROSS-CONNECT SWITCHING SYSTEM WITH BRIDGING, TEST ACCESS AND REDUNDANCY



(57) Abstract: In one embodiment, a scalable cross-connect switching system and its corresponding method perform a bridging operation by splitting the incoming light signal into at least a first bridged light signal and a second bridged light signal. The first bridged light signal has a power level equal to or substantially greater than a power level of the second bridged light signal. The disproportionate power levels provide low-loss bridging. Light signals based on these bridged light signals are routed through multiple switch fabrics which provide redundancy in case of failure by switching within the switch fabric. To detect failures, a test access port is configured for monitoring multiple optical paths.

WO 01/33897 A3



DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW.

**Published:**

— with international search report

**(88) Date of publication of the international search report:**  
22 November 2001

**(48) Date of publication of this corrected version:**  
16 May 2002

**(84) Designated States (regional):** ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

**(15) Information about Correction:**

see PCT Gazette No. 20/2002 of 16 May 2002, Section II

*For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

AN OPTICAL CROSS-CONNECT SWITCHING SYSTEM WITH BRIDGING,  
TEST ACCESS AND REDUNDANCY

CROSS REFERENCE TO RELATED APPLICATIONS

- 5           This non-provisional U.S. Patent Application claims the benefit of U.S. Provisional Patent Application No. 60/162,936 entitled "OPTICAL CROSSCONNECT WITH OPTICAL TO ELECTRICAL CONVERTERS" filed on November 2, 1999 by inventor Rajiv Ramaswami; and also claims the benefit of U.S. Provisional Patent Application No. 60/170,094 entitled "OPTICAL
- 10   CROSSCONNECT WITH BRIDGING, TEST ACCESS AND REDUNDANCY" filed on December 10, 1999 by inventors Rajiv Ramaswami and Robert R. Ward; and also claims the benefit of U.S. Provisional Patent Application No. 60/170,095 entitled "OPTICAL CROSSCONNECT WITH LOW-LOSS BRIDGING, TEST ACCESS AND REDUNDANCY" filed on December 10, 1999 by inventors
- 15   Steven Clark and Rajiv Ramaswami; and also claims the benefit of U.S. Provisional Patent Application No. 60/170,093 entitled "1+1 OPTICAL PROTECTION USING OPTICAL CROSSCONNECT" filed on December 10, 1999 by inventors Rajiv Ramaswami and Robert R. Ward; and also claims the benefit of U.S. Provisional Patent Application No. 60/170,092 entitled
- 20   "SIGNALING INTERFACE BETWEEN OPTICAL CROSSCONNECT AND ATTACHED EQUIPMENT" filed on December 10, 1999 by inventor Rajiv Ramaswami; and also claims the benefit of U.S. Provisional Patent Application No. 60/186,108 entitled "1:N PROTECTION BETWEEN CLIENTS AND ALL-OPTICAL CROSSCONNECTS" filed on March 1, 2000 by inventors Kent
- 25   Erickson, Subhashini Kaligotla, and Rajiv Ramaswami; and also claims the benefit of U.S. Provisional Patent Application No. 60/200,425 entitled "OPTICAL CROSSCONNECT SYSTEM" filed on April 28, 2000 by inventors Rajiv Ramaswami, Steve Tabaska, and Robert Ward.

### General Background

Over the last few years, the demand for high-speed communication networks has increased dramatically. In many situations, communication networks are implemented with electrical interconnections. As desired levels of bandwidth and transmission speed for communication networks increase, it will become more and more difficult for electrical interconnections to satisfy these levels.

Optical fiber offers a solution to the difficulties affecting conventional electrical interconnections. For example, optical fiber is less susceptible to inductive or even capacitive coupling effects as electrical interconnections. In addition, optical fiber offers increased bandwidth and substantial avoidance of electromagnetic interference. The potential advantages of optical fiber becomes more important as the transmission rates increase.

Albeit local or global in nature, many communication networks feature hybrid, optical-electrical semiconductor circuits that employ photodetectors, electrical switches, optical modulators and/or lasers. To handle greater data traffic, an alternative approach has been to employ an optical cross-connect switch, which performs switching operations of light pulses or photons (referred to generally as "light signals") without the need for converting and reconverting signals between the optical domain to the electrical domain. However, conventional optical cross-connect switches are still subject to a wide variety of disadvantages.

One disadvantage is that traditional optical cross-connect switches may not offer any protective features against damage to the optical fiber (facility protection) and against equipment failures, namely failures within the optical cross-connect switch itself. One protective feature may be redundancy. Moreover, traditional optical cross-connect switches do not provide one or more of the following: (1) test access capability to non-intrusively monitor the light signals passing through the cross-connect as well as performance monitoring of these light signals; (2) automatic determination of the topology of the communication network; or (3) low-loss bridging capabilities as described below.

### SUMMARY

In general, one embodiment of the present invention relates to a scalable cross-connect switching system and its corresponding method of performing a bridging operation by splitting the incoming light signal into at least a first bridged light signal and a second bridged light signal. The first bridged light signal has a power level equal to or substantially greater than a power level of the second bridged light signal. The disproportionate power levels provide low-loss bridging. Light signals based on these bridged light signals are routed through multiple switch fabrics, which provide redundancy in case of failure by switching within the switch fabric. To detect failures, a test access port may be configured for monitoring multiple optical paths through an optical-to-electrical (O/E) conversion and monitoring device in lieu of test access ports for assigned for each I/O port.

Other aspects and features of the present invention will become apparent to those ordinarily skilled in the art upon review of the following description of specific embodiments of the invention in conjunction with the accompanying claims and figures.

### BRIEF DESCRIPTION OF THE DRAWINGS

The features and advantages of the present invention will become apparent from the following detailed description of the present invention in which:

Figure 1 is a simplified overview of an exemplary embodiment of an optical cross-connect switching system.

Figure 2 is a first exemplary embodiment of an optical cross-connect switching system of Figure 1.

Figure 3 is an exemplary embodiment of the optical fiber switch matrices forming an optical switch core of Figure 2.

Figure 4 is an exemplary embodiment of mirror arrays forming an optical switch matrix of Figure 3.

Figure 5 is an exemplary embodiment of an I/O subsystem featuring a plurality of I/O port modules.

Figure 6 is an exemplary embodiment of a data path for the transfer of light between I/O port modules and multiple fiber optical switch cores of Figure 2.

5        Figure 7 is an exemplary embodiment of a control path featuring the interconnections between the I/O port module and servo modules.

Figure 8 is an exemplary embodiment of the I/O port module of Figures 6 and 7 illustrating a data propagation circuit and a control circuit.

10       Figure 9 is an exemplary embodiment of multiple ports of I/O modules in communication with optical switches controlled by servo modules.

Figure 10 is an exemplary embodiment of an I/O port configured as a test access port.

Figure 11 is an exemplary embodiment of a servo module of the optical cross-connect system of Figure 1.

15       Figure 12 is an exemplary block diagram of a redundant architecture of the optical cross-connect switching system of Figure 1.

Figure 13 is a first exemplary embodiment of a bridging technique associated with an optical cross-connect switching system.

20       Figure 14 is a second exemplary embodiment of a bridging technique associated with an optical cross-connect switching system.

Figure 15 is a third exemplary embodiment of a bridging technique associated with an optical cross-connect switching system.

Figure 16 is an exemplary block diagram of an optical cross-connect switching system utilizing the bridging technique.

25       Figure 17 is an exemplary block diagram of a 1:K Protection Scheme for equipment redundancy.

Figure 18 is a first exemplary embodiment for providing test access functionality through redundancy.

30       Figure 19 is a second exemplary embodiment for providing test access functionality through additional switching.



Figures 20A-20G are exemplary embodiments of an optical cross-connect switching system utilizing a first type of test port/monitor module.

Figure 21 is an exemplary embodiment of an optical cross-connect switching system utilizing a second type of test port/monitor module.

5        Figure 22 is an exemplary embodiment for performance monitoring and topology discovery utilizing a test access port.

Figure 23 is a first exemplary embodiment of a low-loss bridging technique utilized by a first I/O port module under normal operating conditions.

10       Figure 24 is an exemplary embodiment of the low-loss bridging technique of Figure 23 upon failure of an optical switch.

Figure 25 is a second exemplary embodiment of a low-loss bridging technique utilized by a first I/O port module under normal operating conditions.

Figure 26 is an exemplary embodiment of the low-loss bridging technique of Figure 25 upon failure of an optical switch.

15       Figure 27 is a third exemplary embodiment of a low-loss bridging technique utilized by a first I/O port module under normal operating conditions.

#### DETAILED DESCRIPTION

20       Herein, the exemplary embodiments of the present invention relate to a scalable, optical cross-connect switching system and associated techniques to perform bridging and test access functionality in order to protect against facility and equipment failures. These embodiments are not exclusive; rather, they merely provide a thorough understanding of the present invention. Well-known circuits are not set forth in detail in order to avoid unnecessarily obscuring the  
25       present invention.

      Herein, the exemplary embodiments of the present invention relate to a scalable, optical cross-connect switching system. The described embodiments should not limit the scope of the present invention, but rather are intended to provide a thorough understanding of the present invention. Certain well-known  
30       circuits are not set forth in detail in order to avoid unnecessarily obscuring the present invention.

In the following description, certain terminology is used to describe various features of the present invention. For example, a "module" includes a substrate normally formed with any type of material or materials upon which components can be attached such as a printed circuit board or a daughter card for example. Examples of a "component" include an optical switch, a processing unit (e.g., Field Programmable Gate Array "FPGA", digital signal processor, general microprocessor, application specific integrated circuit "ASIC", etc.), splitters and the like. A "splitter" is an optical component that performs a bridging operation on an input light signal by splitting that light signal into two or more output light signals. Each module features one or more interfaces to transport information over a link. A "link" is broadly defined as one or more physical or virtual information-carrying mediums that establish a communication pathway such as, for example, optical fiber, electrical wire, cable, bus traces, wireless channels and the like. "Information" can be voice, data, address, and/or control in any representative signaling format such as light signals (e.g., light pulses or photons).

#### I. General Architectural Overview

Referring to Figure 1, an exemplary embodiment of a simplified overview of an optical cross-connect switching system 100 is shown. Herein, the optical cross-connect switching system 100 comprises three basic units: a switch subsystem 110, a switch control subsystem 120 and an input/output (I/O) subsystem 130. In one embodiment, the modular architecture of the switch subsystem 110, by a method of having replaceable optical switch cores, provides for switch subsystem maintenance in the event of failure within the switch subsystem 110. It is conceivable that further modularity could be achieved by having replaceable subsections within, thus providing for switch matrix maintenance in the event of failure within a switch matrix itself. The modular architecture of both the switch control subsystem 120 and the I/O subsystem 130, each handling a small number of I/O ports in the system 100, provides scalability to the optical cross-connect switching system 100. Thus, additional I/O ports may

be subsequently added to the optical cross-connect switching system 100 by adding or removing input/output (I/O) port modules (described below).

The switch subsystem 110 includes optical switches for routing light signals. In one embodiment, the optical switches forming the switch subsystem 110 are micro-machined mirrors; however, it is contemplated that other switch fabrics may be used such as liquid crystal technology. The I/O subsystem 130 receives external light signals 140 and transfers these signals to the switch subsystem 110. The switch control subsystem 120 controls the configuration of the switch subsystem 110 (e.g., mirror orientation) and performs certain monitoring functions. The interconnectivity between the switch subsystem 110, the switch control subsystem 120 and the I/O subsystem 130 includes redundancy so that no equipment failures would cause complete disablement of the system 100.

Referring now to Figure 2, a first exemplary embodiment of an optical cross-connect switching system 100 is shown. In general, the optical cross-connect switching system 100 is a matrix-based optical cross-connect with associated I/O port modules. More specifically, the optical cross-connect switching system 100 is collectively formed by a plurality of platforms 205, 206 and 207 in communication with each other, although the implementation of the switching system 100 as a single platform is another embodiment. Herein, each platform 205, 206 and 207 includes a frame 210 (e.g., a rack) that physically supports I/O port modules forming the I/O subsystem 130 as well as servo modules, servo control modules and/or network control modules of the switch control subsystem 120. The modules are arranged either horizontally or vertically within each platform 205, 206 and 207 and can be individually removed or installed without interfering with immediately adjacent modules.

In addition, the frame 210 may also physically support one or more optical switch cores, each including one or more optical switches (e.g., one type of "optical switch" may be two or more mirrors operating in tandem). Herein, a collection of one or more optical switches may also be generally referred to as

“switch fabric.” Thus, the terms switch fabric and optical switch core(s) are interchangeable.

As shown in this embodiment, the first platform 205 comprises (i) a plurality of I/O port modules 215 associated with the I/O subsystem 130 of Figure 1, (ii) a plurality of servo modules 225 and a management control subsystem (MCS) 235 associated with switch control subsystem 120 of Figure 1, and (iii) a first (primary) optical switch core 240 associated with switch subsystem 110 of Figure 1. Similarly, the second platform 206 comprises a plurality of additional I/O port modules 245, a plurality of (redundant) servo modules 250, a management control subsystem 255, and a second (redundant) optical switch core 260. The third platform 207 comprises a plurality of servo modules 265 that control various mirrors of the first and second optical switch cores 240 and 260, which correspond to additional ports associated with I/O port modules 245. Additionally, a light path test signal generator(s), a light path signal monitor(s), circuit breakers and/or alarm visual indication 270 may be located within the third platform 207. For clarity, the elements forming the first platform 205 are described since these elements may be found in the second and/or third platforms 206 and 207.

As shown in both Figures 2-4, the first optical switch core 240 includes a first optical switch matrix 241 and a second optical switch matrix 242. These matrices 241 and 242 are collectively positioned to route light signals 250 between a port of a source I/O port module  $215_s$  (“s” is a positive whole number) and a port of a destination I/O port module  $215_d$  (“d” is a positive whole number), both modules located in any of the platforms 205, 206 and 207 as shown in detail in Figure 3. Although a two-bounce routing technique is shown, it is contemplated that a three-bounce routing technique may be used in which the “second bounce” mirror, as optionally shown through dashed lines, is positioned to assist in routing light signals from one optical switch matrix to another.

As shown in Figure 4, one embodiment for each of the optical switch matrices 241 and 242 includes multiple arrays 300 of micro-machined mirrors. Each mirror (e.g., mirror 310) features a mirrored surface 311 and torsional

flexures 320 and 330 that enable the mirror 310 to adjust its physical orientation to reflect incoming light signals in any selected direction. Herein, both the first and second optical switch matrices 241 and 242 include Q micro-machined mirrors, where "Q" is less than or equal to the maximum number of I/O ports that  
5 can be supported by the optical cross-connect switching system 100. For this embodiment, "Q" is greater than or equal to 64 but less than or equal to 1152 ( $64 \leq Q \leq 1152$ ). However, the present invention is not limited to any maximum number of mirrors or I/O ports. It is contemplated, however, that the number of mirrors employed within the first and second optical switch matrices 241 and 242  
10 may differ.

As generally shown in Figures 2, 5 and 6, the plurality of I/O port modules 215 features two groups 216 and 217 of I/O port modules. Each group, such as group 216 or 217 for instance, includes up to seventy-two (72) quad-port I/O port modules as shown in Figure 5 that receive power from one or more power supply  
15 modules denoted herein as "PSM". The components forming an I/O port module is described below and shown in Figures 8 and 9. Thus, each I/O port module, such as I/O port module 215, for example, features an external interface 400 for a plurality of I/O ports 410 (e.g., four I/O ports). An I/O port 410 features a duplex socket that is adapted to receive a duplex pair of optical fiber links, one optical  
20 fiber link routes a light signal to the I/O port 410 while the other routes light signals from the I/O port 410. This support bi-directional optical connections. There is a small percentage (e.g., less than 15%) of these I/O ports, however, that may be assigned as test access ports as described below.

Moreover, as shown in Figure 6, upon receiving an incoming light signal  
25 over an optical fiber link 420, the I/O port module 215, performs a bridging operation by splitting the incoming light signal into multiple (two or more) bridged light signals for routing to the first and second optical switch cores 240 and 260. The bridged light signals are routed through an internal optical interface 425 featuring optical fiber ribbon links 430 and 440. For this embodiment, the  
30 "optical fiber ribbon links" are ribbon cables having multiple optical fiber lines (e.g., two lines from each I/O port). The first optical switch core 240 provides a

primary optical path. The second optical switch core 260 provides a redundant optical path in the event the first optical switch core 240 is not operating properly. The optical switch cores 240 and 260 route the bridged light signals to a selected port of a destination I/O port module (e.g., I/O port module 215<sub>d</sub>) via optical fiber ribbon links 450 and 460.

Upon receiving light signals from both the first and second optical switch cores 240 and 260, the I/O port module 215<sub>s</sub> provides small percentage optical tap signals of the received light paths to the respective servo modules, which in turn determine light signal quality. The respective servo modules will convey light signal quality for each respective light path to the I/O port module, using a digital protocol over an electrical communication link 505 to the I/O port module as shown in Figure 7. The I/O port module 215<sub>s</sub> will in turn, determine (i.e. select) which light signal has the higher signal quality and outputs that signal via interface 400. In most cases, the signal quality of the two light paths presented to the I/O port module will be of the same signal quality and each may have a relatively low optical loss of approximately seven decibel (7 decibels "dB") or less. For instance, a 3dB loss caused by a splitter, approximately 3dB loss caused by an optical switch core and approximately a 1dB loss at an optical switch as described below.

Referring now to Figures 2 and 7, each servo module 225 is configured to receive optical tap signals from one or more I/O port modules. Herein, servo module 225<sub>i</sub> is configured to receive optical tap signals via link 500 from I/O port module 215<sub>s</sub>. These optical tap signals provide feedback to indicate a percentage of the bridged light signals and also allow for light to be injected under certain conditions. In response to receiving optical tap signals via link 500, the servo module 225<sub>i</sub> provides mirror control signals over link 510 to the first optical switch core 240. The mirror control signals are routed via a unique communication path to an optical switch (e.g., a micro-machined mirror) and are associated with the port of the I/O port module 215<sub>s</sub> through which the incoming light signal was routed. The mirror control signals are used for proper adjustment of the physical orientation of the mirror.

The I/O port module 215<sub>d</sub> provides optical tap signals over link 530 to servo module 225<sub>j</sub>. In response to receiving the optical tap signals from I/O port module 215<sub>d</sub>, the servo module 225<sub>j</sub> provides mirror control signals via link 540 to the first optical switch core 240. The mirror control signals are routed via a  
5 unique communication path to a micro-machined mirror associated with a selected port of the I/O port module 215<sub>d</sub> from which the light signal would be output. Herein, sensing the optical tap (feedback) signals, the servo module 225<sub>j</sub> determines the light signal quality and conveys light signal quality information for each light path using a digital protocol over (electrical) link 535. Thereafter, the  
10 I/O port module 215<sub>d</sub> chooses the selected port (i.e. port having the best light signal quality).

Collectively, the optical tap signals, mirror control signals and light signal quality information, which are routed over links 500, 510, 530, 540, 505 and 535, are used by servo modules 225<sub>i</sub> and 225<sub>j</sub> for adjustment of the physical orientation  
15 of mirrors to make a connection between I/O port module 215<sub>s</sub> and 215<sub>d</sub>.

Additionally, I/O port modules 215<sub>s</sub> and 215<sub>d</sub> also transfer optical tap signals via links 520 and 550, respectively. Similar to the above description, these optical tap signals establish the redundant optical path by altering the physical orientation of one or more micro-machined mirrors of the second optical switch  
20 core 260 using mirror control signals over links 560 and 570 and light signal quality information via links 525 and 555.

In the event that no optical power is presented to the I/O port module 215<sub>s</sub>, a substitute light signal may be injected from the servo module 225<sub>i</sub> via link 500. An alignment laser may be used as shown in Figure 11 described below. This  
25 process of light substitution allows for connection establishment and verification when no input light is present to the I/O port module 215<sub>s</sub>. The substitute light source can be within the same wavelength range (e.g. 1100 nanometers "nm" - 1700 nm) as the allowed input light signal range. In one embodiment, the light source or method of injection would be chosen to not interfere with attached  
30 equipment's select operational wavelength range. Choosing a different

wavelength source on the servo module and/or a wavelength specific splitter and/or filter on the I/O port module could do this particular embodiment.

The management control subsystem 235 (see Figure 2) enables communications between two or more servo modules placed within the same or different platforms. The management control subsystem 235 includes at least one servo control module 236 and an optional network control module 238. In one embodiment, the servo control module (SCM) 236 ensures communication between at least servo modules 225<sub>i</sub> and 225<sub>j</sub> that control mirrors associated with the first optical switch core 240. The network control module (NCM) 238 manages the execution of connection configurations for the whole cross-connect switching system and ensures communications between multiple servo control modules 236 and 237. The same architecture is used to control optical switches within the second optical switch core 260 as shown.

## II. General Architecture of the I/O Port Modules

Referring now to Figures 8 and 9, an exemplary embodiment of an I/O port module (e.g., I/O port module 215<sub>s</sub>) and its communications over optical switch cores 240 and 260 is shown. I/O port module 215<sub>s</sub> includes a data propagation circuit 600 for each I/O port and a control circuit 670. Thus, in the event that the I/O port module 215<sub>s</sub> is configured with four I/O ports, four data propagation circuits are implemented on the I/O port module 215<sub>s</sub> as represented. Only the data propagation circuit 600 for one of the I/O ports of I/O port module 215<sub>s</sub> (e.g., i<sup>th</sup> I/O port) is shown in detail for clarity sake.

In one embodiment, the data propagation circuit 600 comprises an optical switch 610, a (passive) splitter 620 and a plurality of tap couplers 630<sub>1</sub>-630<sub>4</sub>. The plurality of tap couplers 630<sub>1</sub>-630<sub>4</sub> correspond to the pairs of optical fibers found in optical fiber ribbon links 430 and 440. The control circuit 670 comprises a programmable memory 680, a processing unit 685 and status identification components 690.



As shown, each port of the I/O port module 215<sub>s</sub> supports full-duplex communications. Thus, an incoming light signal 606 received over port 605 is routed to the splitter 620. The splitter 620 effectively performs a bridging operation by splitting the incoming light signal 606 into bridged light signals 625, which collectively have the same power level (energy) as the light signal 606. In one embodiment, when the splitter 620 is a 50/50 splitter, the bridged light signals 625 have equal power levels. However, it is contemplated that splitter 620 may produce bridged light signals 625 having disproportionate power levels.

The bridged light signals 625 are routed through the tap couplers 630<sub>1</sub> and 630<sub>2</sub>. Attached to servo module 225<sub>i</sub> and servo module 225<sub>i+1</sub> via optical tap links 500 and 520, the tap couplers 630<sub>1</sub> and 630<sub>2</sub> are used to monitor the power level of light signals 635 and 636 propagating through optical fiber ribbon links 430 and 440 (referred to as "outgoing light signals"). This enables the servo modules 225<sub>i</sub> and 225<sub>i+1</sub> to verify the connectivity of the splitter 620 to optical fiber ribbon links 430 and 440 and to detect unacceptable variances in optical performance of the light signal. As shown for this embodiment, the tap couplers 630<sub>1</sub> and 630<sub>2</sub> may separate the bridged light signals into signals having disproportionate power levels in order to maximize the power levels of the outgoing light signals propagating through optical fiber ribbon links 430 and 440. For example, where the tap couplers 630<sub>1</sub> and 630<sub>2</sub> may operate as 90/10 splitters, the outgoing light signals 635 and 636 have ninety (90%) of the total power level of the bridged light signal while the optical tap signals 640 and 641 have only ten percent (10%).

Referring to Figure 8, tap couplers 630<sub>3</sub> and 630<sub>4</sub> are configured to receive incoming light signal 650 and 655 via optical fiber ribbon links 430 and 440, respectively. The tap couplers 630<sub>3</sub> and 630<sub>4</sub> effectively separate the light signals 650 and 655 into corresponding pairs of light signals having disproportionate power levels (e.g., signals 661, 662 and 663, 664). Signals 662 and 664 having the lower power level are provided to the servo module 225<sub>i</sub> and servo module 225<sub>i+1</sub> via links 500 and 520 for monitoring the power levels of the light signals 661 and 663, without the light signals 661 and 663 experiencing substantial signal degradation. The signals 662 and 664 may be light signals that undergo O/E

conversion at the I/O port module 215<sub>s</sub> or at the servo modules 225<sub>i</sub> and 225<sub>i+1</sub> as shown in Figure 11. The tap couplers 630<sub>3</sub> and 630<sub>4</sub> are shown as 90/10 splitters; however, tap couplers 630<sub>3</sub> and 630<sub>4</sub> may be any selected ratio, including 50/50.

The light signals 661 and 663 are routed to the optical switch 610 of a  
5 destined I/O port. The control circuit 650 on the I/O port module 215<sub>s</sub> determines which of the pair of light signals 661 and 663 has the best signal quality based on conveyed light signal quality information from the servo modules via links 505 and 525 as briefly described below. Parameters used to determine light signal quality include measured optical signal intensity/power, extinction ratio, and the  
10 like. The light signal quality information to the I/O port module may be conveyed as failed due to the servo module service operations, high bit error rate, an external light path has failed, and the like. The light signal 661 or 663 with the best signal quality is output through the I/O port 605. Of course, it is contemplated that the light signal output operations described for I/O port i are applicable to I/O  
15 port j as shown.

It is contemplated that an I/O port of the I/O port module 215<sub>s</sub> may be configured as a test access port. A "test access port" is an I/O port that is used for monitoring light signals routed through another port. Normally, the test access port receives a portion of the power level of a light signal routed through a  
20 selected optical switch (e.g., micro-machined mirror). For example, as shown in Figure 10, an I/O port 218 of the I/O port module 215<sub>s</sub> is configured for coupling with a monitoring device 219 (e.g., a bit error rate "BER" monitor in combination with an optical-electrical "O/E" converter, etc.) to monitor a power level of a light signal routed to the i<sup>th</sup> I/O port from an optical switch.

25 Referring back to Figure 8, the control circuit 670 comprises the programmable memory 680 in communication with the processing unit 685 (e.g., FPGA). The programmable memory 680 contains software and other information used by the processing unit 685 to provide selection of the best quality signal based on digital electrical signaling from servo module 225<sub>i</sub> and servo module  
30 225<sub>i+1</sub> over links 505 and 525, respectively. Also, programmable memory 680 includes information used by the processing unit 685 to control the state of the

status identification components 690 (e.g., light emitting diodes “LEDs”). The state of the status identification components 690 identifies (1) whether each I/O port is operational and/or (2) whether the I/O port module is operational. The processing unit 685 is further in communications with optical switches of each data propagation circuit employed in the I/O port module 215, in order to receive switch status signals and provide switch control signals. As shown for clarity, processing unit 685 provides optical switch 610 with switch control signals for receiving switch status signals and selecting either light signal 661 or light signal 663.

10

### III. General Architecture of the Servo Modules

Referring now to Figure 11, an exemplary embodiment of the servo module (e.g., servo module 225<sub>i</sub>) is shown. In one embodiment, the servo module 225<sub>i</sub> comprises two separate modules in communication over connectors 705 and 790. These separate modules are referred to as an “optical detector module” 700 and a “servo mirror control module” 750.

The optical detector module 700 comprises a first processing unit 710, memory 715, a plurality of detection/modulation (DM) circuits 716 and status identification components 717. As shown, the optical detector module 700 features sixteen (16) DM circuits 716 to support four (4) quad-port I/O port modules. Each DM circuit 716 includes an analog-to-digital (A/D) converter 720, a laser 725, optical-electrical (O/E) detectors 730 and 731, and optional amplifiers 735 and 736.

The servo mirror control module 750 comprises a second processing unit 755, a memory 760, a plurality of mirror signal detection and generation (SDG) circuits 761, a third processing unit 775 and status identification components 795. The SDG circuits 761 correspond in number to the DM circuits 716 of the optical detector module 700. Each SDG circuit 761 features an A/D converter 765, a digital-to-analog (D/A) converter 770, hinge position sensors 780-781 and high voltage (HV) mirror drivers 785-786.

30

As shown in Figure 11, the optical detector module 700 is removably coupled to the servo mirror control module 750. This allows the optical detector module 700 to be "hot swapped" from a backplane, which features connectors 705 and 790 connecting the optical detector module 700 to the servo mirror control module 750, without disrupting the servo mirror control module's 750 ability to hold the mirrors in their existing positions for an extended period of time. This "hot swapping" of the optical detector module 700 allows for repair or upgrade of the optical detector module 700. Optical detector module 700 receives optical tap (feedback) signals 640 and 662 from one or more I/O port modules (e.g., I/O port module 215, via link 500) and can transmit optical control signals 726 from the laser 725 for alignment of light signals transferred between two I/O port modules. The optical tap signal 640 is based on an input light signal that is routed to the switch fabric.

More specifically, with respect to servo module 225<sub>i</sub>, the O/E detectors 730 and 731 are coupled to tap couplers 630<sub>1</sub> and 630<sub>3</sub> of Figures 8-9. More specifically, the O/E detectors 730 and 731 are configured to detect incoming, optical tap signals 640 and 662, convert the optical tap signals 640 and 662 into corresponding electrical control signals measuring a power level of the outgoing light signal, and optionally route the electrical control signals to corresponding amplifiers 735 and 736. The (amplified) electrical control signals are provided to the A/D converter 720. The A/D converter 720 converts the electrical control signals into measured power sense signals 644 of a digital form. The measured power sense signals 644 are provided to the first processing unit 710.

Herein, the first processing unit 710 may perform a number of operations based on the electrical control signals such as threshold crossing, LOS integration, input/output power ratio analysis and the like. Software and other information necessary for performing these operations may be obtained from the memory 715 by the first processing unit 710. Herein, memory 715 can be non-volatile memory such as non-volatile random access memory, electrically erasable programmable read only memory (EEPROM) and the like.

The optical detector module 700 includes multiple status identification components 717 (e.g., light emitting diodes "LEDs"). A first LED 718 identifies whether any operational faults associated with the servo module 225<sub>i</sub> have occurred. A second LED 719 indicates when the optical detector module 700 is in  
5 service.

Referring still to Figure 11, in this embodiment, the servo mirror control module 750 comprises the second processing unit 755 that is coupled to both the first processing unit 710 and the third processing unit 775. For instance, in order to adjust the switch fabric in response to the measured power sense signals 644,  
10 the second processing unit 755 receives information representative of the measured power sense signals from the first processing unit 710 via connectors 705 and 790. The second processing unit 755 further receives information representative of measured power sense signals for the light signal at a targeted I/O port. This information is provided by the SCM 236 over link 580 via the third  
15 processing unit 775. This assists in reducing errors in adjusting the torsional flexures of the mirrors.

Upon receipt of these measured power readings, the second processing unit 755 controls a particular SDG circuit corresponding to a mirror associated with the I/O port over which the tapped light signal was routed. The control  
20 involves slight mirror orientation adjustments if the power level readings differ substantially.

In particular, a first hinge position sensor 780 senses a position of a mirror via link 510 from the first optical switch core 240. The sensed position signal is routed to the A/D converter 765, which is subsequently placed in a digital format  
25 before routing to the second processing unit 755. When the servo module 225<sub>i</sub> is adjusting the switch fabric, the second processing unit 755 transfers mirror control signals to the D/A converter 770. The mirror control signals are routed to HV driver 785 and applied to a selected mirror of the first optical switch core in order to adjust the amount of torsional flexure along a first dimensional plane (e.g., X-axis). This is accomplished to minimize the loss experienced by the light signal.  
30

A second hinge position sensor 781 senses a position of a mirror for the first optical switch core along a second dimensional plane (e.g., Y-axis). The sensed position signal is routed to the A/D converter 765, which is subsequently placed in a digital format before routing to the second processing unit 755. When  
5 the servo module 225<sub>i</sub> is adjusting the switch fabric, the second processing unit 755 transfers mirror control signals to the D/A converter 770. The mirror control signals are routed to HV driver 786 and are applied to the selected mirror of the first optical switch core in order to adjust the amount of torsional flexure along the second dimensional plane. The specifics of the hinge position sensors 780 and  
10 781 are described in a PCT application entitled "Micromachined Members Coupled for Relative Rotation By Torsional Flexure Hinges" (International Publication No. WO 00/13210) published on or around March 9, 2000.

In another embodiment, when I/O port module 215<sub>s</sub> is the destination of a light signal, the second processing unit 755 receives information representative of  
15 the measured power sense signals associated with the optical tap signal 662 that has been analyzed by the first processing unit 710. The optical tap signal 662 is based on an output light signal being routed from an I/O port. In this situation, the third processing unit 775 receives information associated with the measured power sense signals from a source I/O port as reported by SCM 236 over link 580.  
20

#### IV. Redundant Architecture of the Optical Cross-Connect Switching System

Referring now to Figure 12, a block diagram of an alternative embodiment  
25 of the architecture of the optical cross-connect switching system of Figure 1 is shown which includes redundant protection capabilities. Redundancy is desired in order to increase the reliability of such an optical cross-connect switching system. Aside from the I/O port modules, all other modules are duplicated to obtain the desired redundancy. Thus, it is necessary for light signals from a  
30 source I/O port module 215<sub>s</sub> to be routed to a destination I/O port module 215<sub>d</sub> through two optical paths, namely a primary optical path 800 using a first optical

switch core 240 and a redundant optical path 810 using a second optical switch core 260.

With respect to the primary optical path 800, a servo module 225<sub>i</sub> is connected to both the source I/O port module 215<sub>s</sub> and the first optical switch matrix (not shown) of the first optical switch core 240. In particular, the servo module 225<sub>i</sub> controls the physical orientation of a mirror of the first optical switch matrix that corresponds to the source I/O port module 215<sub>s</sub>. To establish and maintain the primary optical path 800 for the light signal, the servo module 225<sub>i</sub> needs to communicate with other servo modules such as servo module 225<sub>j</sub>. Thus, a servo control module (SCM) is implemented to support such communications, possibly through a time-slot switching arrangement.

As shown, the SCMs 236<sub>1</sub>-236<sub>2</sub> are also duplicated so that each servo module 225 is connected to at least two SCMs 236<sub>1</sub>-236<sub>2</sub>. Thus, in the event that the SCM 236<sub>1</sub> fails, the primary optical path 800 remains intact because communications between the servo modules 225<sub>i</sub> and 225<sub>j</sub> are maintained via redundant SCM 237<sub>1</sub>. The transfer is accomplished by temporarily halting the adjustment of (i.e. freezing) the mirrors inside the first optical switch core 240 while control is transferred from SCM 236<sub>1</sub> to SCM 237<sub>1</sub>. The SCMs 236<sub>1</sub> and 237<sub>1</sub> associated with the first optical switch core 240 are in communication via a network control modules (NCMs) 238<sub>1</sub> and 238<sub>2</sub> for example.

With respect to the redundant optical path 810, a servo module 225<sub>i+1</sub> is connected to both the source I/O port module 215<sub>s</sub> and one or more mirror(s) of a first optical switch matrix (not shown) of the second optical switch core 260. Another servo module 225<sub>j+1</sub> is connected to both the destination I/O port module 215<sub>d</sub> and one or more mirror(s) of a second optical switch matrix (not shown) of the second optical switch core 260. The orientation of these mirrors produces the redundant optical path 810.

To establish and maintain the redundant optical path 810 for the light signal, a SCM 236<sub>2</sub> may be implemented with a dedicated time-slot switching arrangement in order to support continuous communications between the servo module and another redundant servo module associated with the destination I/O

port module. As shown, the SCM 236<sub>2</sub> is also duplicated so that each servo module 225<sub>i+1</sub> and 225<sub>j+1</sub> is connected to at least two SCMs 236<sub>2</sub> and 237<sub>2</sub>. Thus, the redundant optical path 810 is maintained even when one of the SCMs 236<sub>2</sub> and 237<sub>2</sub> fails. The SCMs 236<sub>2</sub> and 237<sub>2</sub> associated with the second optical switch core 260 communicate via the first NCM 238<sub>1</sub> and the second NCM 238<sub>2</sub>, respectively. The second NCM 238<sub>2</sub> is in communication with the first NCM 238<sub>1</sub> to allow all SCMs and servo modules to communicate for coordination of the primary optical path 800 and the redundant optical path 810.

10           V.     Detailed Overview of the Bridging Technique for the Optical Cross-Connect Switching System

Referring now to Figures 13-16, exemplary embodiments of the bridging technique for redirecting signals to prevent against disruption of an optical path of the optical cross-connect switching system due to facility or equipment failures is shown.

A first exemplary embodiment of a bridging technique utilized by a source I/O port module 900 is shown in Figure 13. In particular, a port 905 of the source I/O port module 900 receives a light signal 910 and subsequently routes the light signal 910 to one or more splitters 920. For clarity sake, one or more splitters are referred to in a singular tense as "splitter".

Herein, the splitter 920 effectively produces two outgoing light signals with generally equivalent power (energy) levels, which are routed over links 925 and 930. In one embodiment, the collective power level measured for the outgoing light signals is generally equal to the power level of the light signal 910 minus the additional energy loss caused by the splitter 920 (e.g., approximately 3dB).

The two outgoing light signals are subsequently routed over links 925 and 930 over to different inputs of a switch fabric 935. In one embodiment, the switch fabric 935 may be an optical switch core formed with two optical switch matrices of micro-machined mirrors as described above. However, it is contemplated that



the particular configuration of the switch fabric 935 is not relevant to the inventive bridging technique described below.

The switch fabric 935 routes the outgoing light signals over links 940 and 945 to a switch 950 within a destination I/O port module 955. The optical switch  
5 950 is configured to select one of the light signals received over links 940 and 945 based on any number of signal quality parameters such as measured optical signal intensity/power, extinction ratio, and the like. Of course, it is contemplated that certain I/O port modules (e.g., modules 960 and 970) may be implemented within the optical cross-connect switching system but devoid of any bridging  
10 functionality.

As shown in Figure 14, a second exemplary embodiment of a bridging technique utilized by the source I/O port module 900 to separate the original light signal 910 into multiple outgoing light signals which are routed to multiple optical switches is shown. In particular, the port 905 of the source I/O port module 900  
15 receives the light signal 910 and subsequently routes the light signal 910 to the splitter 920. For this embodiment, the splitter 920 effectively produces at least two outgoing light signals with generally equivalent power (energy) levels routed over links 925 and 930. Link 925 provides a first outgoing light signal to the switch fabric 980 while link 930 provides a second outgoing light signal to  
20 another switch fabric 985. Herein, in this embodiment, each switch fabric 980 or 985 includes a switching technology, possibly optical switch matrices as described above. The switch fabric 980 and 985 may be one or more optical switches in the same optical switch core or different optical switch cores.

In response to receiving the first outgoing light signal, the switch fabric  
25 980 routes the same over link 940 to the optical switch 950. The switch fabric 985 routes the second outgoing light signal over link 945 to the optical switch 950. Coupled to both links 940 and 945, the optical switch 950 is configured to select one of the outgoing light signals received over links 940 and 945 based on a number of parameters such as those described above.

30 R ferring now to Figure 15, a third exemplary embodiment of a bridging technique associated with an optical cross-connect switching system is illustrated.

The optical cross-connect switching system (OXC) 1000 comprises one or more optical input ports 1001A-1001N and one or more optical output ports 1002A-1002N provided by the various I/O port modules. The optical cross-connect switching system 1000 includes I/O port modules 1004A-1004N and 1004A'-1004M' that provide bridging for the switch fabric 1010. Bridging means that at least two optical paths are provided between I/O port modules carrying the same light signals. The switch fabric 1010 illustrates exemplary optical signal paths 1015A-1015D and redundant optical signal paths 1015A'-1015D'. If one optical path fails in the switch fabric 1010, the redundant optical path in the switch fabric 1010 continues to handle the data carried by the light signals. For example, if the optical path 1015A fails in the switch fabric 1010, the optical path 1015A' continues to carry the light signals. The redundant optical path 1015A' can be thought as bridging a gap in the optical path 1015A when it fails.

An optical path (fiber break) or the generation of light signals in an optical path (component failure) can fail, terminating the light signal completely or generating bit errors at a high rate over that of the other light signal or optical path. By monitoring the light signal inputs and/or outputs from the optical cross-connect switching system 1000, for example, a determination can be made whether to switch from one light signal in one optical path to another. The optical path and/or light signal in the optical path can fail for a variety of reasons including one or more faulty components or a failure in control.

To generate a redundant optical path in the optical cross-connect switching system 1000, an incoming light signal is input into an input port such as input port 1001A. In one type of I/O port module, illustrated as I/O port module 1004A-1004N (generally referred to as 1004), the incoming light signal is coupled into an optical-to-electrical-to-optical "O/E/O" converter 1007 (referred to as "O/E/O") in the input optical path 1011. The O/E/O 1007 converts the light signal into an electrical signal, which is then converted back into a light signal. The electrical signal is used to monitor the incoming light signals.

In general, the O/E/O 1007 is coupled to an optical splitter 1008 to split the incoming light signal into at least two outgoing light signals on at least two

(split) optical paths 1021A and 1022A. The optical splitter 1008 can be used to split the light signal into more than two split optical paths to provide greater redundancy and reliability if desired but is typically not needed. The optical splitter 1008, in one embodiment, is a passive optical coupler. While the data  
5 signal or pulses of light of the split light signals are the same, the energy level of the incoming light signal can be split equally or unequally into the at least two light signals on the at least two split optical paths 1021A and 1022A.

The at least two split optical paths 1021A and 1022A proceed to the switch fabric 1010 and switched to another I/O port module respectively over the  
10 optical paths 1015A and 1015A' for example. The redundant light signals in the optical paths 1015A and 1015A' are routed into a switch 1009 of the I/O port module 1004B for example over the split paths 1023B and 1024B, respectively. The switch 1009 is an optical switch. As its output, the switch 1009 selects between the at least two outgoing light signals routed over split optical paths  
15 1015A and 1015A'. The selected output of the switch 1009 is routed into the optical output path 1012 of the I/O port module 1004B and the output port 1002B of the optical cross-connect switching system 1000. In the case that one of the two light signals over split optical paths 1015 and 1015A' fails or has errors, the switch 1009 can select the alternate optical path as its output to overcome the path  
20 failure or the errors.

In another type of I/O port module, illustrated by I/O port modules 1004A'-1004M' (generally referred to as 1004'), an incoming light signal at the input port 1001C is first routed into a splitter 1008' in the optical input path 1011. The incoming light signal is split by the splitter 1008' into at least two light  
25 signals routed over at least two (split) optical paths 1021C and 1022C for example. The at least two light signals on the at least two split optical paths 1021C and 1022C are then provided to the switch fabric 1010 for switching. In the switch fabric 1010, the split light signals are routed over different optical paths such as optical paths 1015C and 1015C'. The split light signals over optical paths  
30 1015C and 1015C' are routed into the same switch of an I/O port module such as

switch 1009' of the I/O port module 1004M' via the optical paths 1023M and 1024M for example.

As shown, the switch 1009' is an optical switch. As its output, the switch 1009' selects between the at least two light signals in the at least two split optical paths 1015C and 1015C' for example. The selected output of the optical switch 1009' is routed into the optical output path 1012 of the I/O port module 1004M' and the output port 1002M of the optical cross-connect switching system 1000. In the case that one of the two light signals in the at least two split optical paths fails or has errors, the optical switch 1009' can select the alternate optical path as its output to overcome the path failure or the errors. The output of the optical switch 1009' is coupled into the O/E/O 1007' on the I/O port module 1004M' for regenerating the light signals. With the O/E/O 1007' in the output path, regeneration is performed post split. In this manner, the O/E/Os do not need to be duplicated in the input path and output path for each connection of a communication channel over the optical cross-connect switching system 1000.

The monitoring provided by the O/E/Os 1007 and 1007' in the I/O port modules 1004A-1004N and 1004A' -1004M' in the optical cross-connect switching system 1000, assist in the selection between the at least two light signals in the at least two split optical paths by the optical switches 1009 and 1009', respectively. If the monitoring determines that there is no signal at the output of the optical switch 1009' and it is known that there should be a signal present, the optical switch 1009' can select the alternate path. If the monitoring determines that there is an incoming light signal into the splitter 1008 and it is known that it should be present at the output of the optical switch 1009, the alternate path can be selected.

In either case, the I/O port modules of the optical cross-connect switching system 1000 of Figure 15 split the incoming light signal at an input port into at least two (split) outgoing light signals to propagate over two different optical paths and provide redundancy in how the data signal is routed over the switch fabric 1010. The I/O port modules then select which of the at least two (split)

outgoing light signals to route into an output port of the optical cross-connect switching system 1000.

Referring now to Figure 16, a block diagram of an optical cross-connect switching system 1000 is illustrated. The optical cross-connect switching system 1000 is an alternate embodiment to provide bridging over a switch fabric 1110. The optical cross-connect switching system 1000 has one or more optical input ports 1101A-1101N and one or more optical output ports 1102A-1102N provided by the various I/O port modules.

Using one type of I/O port module, an incoming light signal 1111 is first converted from a light signal in the optical domain into an electrical signal in the electrical domain and fanned out (e.g., electrically split into two equal electrical signals) by coupling to two optical transmitters 1118A and 1118B (e.g., an electrical-to-optical "E/O" converter such as a semiconductor laser). The two optical transmitters 1118A and 1118B convert in parallel the electrical signal into two light signals in the optical domain. The two light signals generated by the two optical transmitters 1118A and 1118B are substantially similar.

The two light signals are then routed through the switch fabric 1110 through differing optical paths 1115A and 1115A'. A selection is then made at the output of the switch fabric 1110 between the two light signals in order to generate the output light signal 1112 from the optical cross-connect switching system 1000. If one path of the two light signals should fail, the opposite path is selected.

Using another type of I/O port module, namely I/O port module 1104A', ..., or 1104M', the incoming light signal is optically split into two split light signals which are routed over the switch fabric 1110. At the output of the switch fabric 1110, the two (split) light signals in the optical domain are coupled into two optical receivers 1128A and 1128B (each an optical to electrical "O/E" converter such as a photodiode) to convert them into two electrical signals respectively in the electrical domain. The two electrical signals are then coupled into multiplexer 1129 to electronically select which one of the two should be transmitted out the output port 1102M of the optical cross-connect switching

system 1000 by an optical transmitter 1127 (e.g., an E/O converter such as a semiconductor laser). The optical transmitter 1127 converts the selected electrical signal in the electrical domain into a light signal in the optical domain.

As shown in Figure 16, the optical cross-connect switching system 1000  
5 can include one or more I/O port modules 1104A-1104N and/or one or more I/P port modules 1104A'-1104M'. In either case, the I/O port modules provide two different optical paths through the optical switch fabric 1110 for the same communication channel connection. For example, optical paths 1115A-1115D are one path for the communication channels while optical paths 1115A'-1115D'  
10 are another both carrying the same data signals. If one optical path should fail generating a gap in the connection, the other path is selected to bridge the gap and to allow a continuous flow of data for the given communication channel connection. Bridging in this manner increases the reliability of the optical cross-connect switching system 1000.

15 The I/O port modules 1104A-1104N include an optical receiver 1117 (e.g., an O/E converter such as a photodiode) which is coupled to a pair of optical transmitters 1118A and 1118B (e.g., an electrical-to-optical "E/O" converter such as a semiconductor laser) in the input path 1111. Thus, in the input path 1111 of the I/O port modules 1104A-1104N, an optical-electrical-optical conversion  
20 (O/E/O) is performed. In the output path 1112, the I/O port modules 1104A-1104N include an optical switch 1109 to select between two light signals. The optical transmitters 1118A and 1118B generate the two parallel light signals that are routed over two paths in the switch fabric 1110 such as optical paths 1115A and 1115A'. The optical switch 1109 selects between the two parallel light  
25 signals to generate one as the output of the optical cross-connect switching system 1000 on an output port. If the selected path should fail, the optical cross-connect switching system 1000 switches to the other light signal carried over the other optical path.

The I/O port modules 1104A'-1104M' include an optical splitter 1108 in  
30 the input path 1111 to split the incoming light signal into two (split) outgoing light signals. The two outgoing light signals are routed to the switch fabric 1110 over

two separate optical paths. For example, the I/O port module 1104A' would be coupled for routing the split, outgoing light signals over optical paths 1115C and 1115C' of the switch fabric 1110. In the output path 1112, the I/O port module 1104A'-1104M' include the pair of optical receivers 1128A and 1128B, the  
5 multiplexer 1129, and the optical transmitter 1127 as previously described.

The pair of optical receivers 1128A and 1128B (e.g., an O/E converter such as a photodiode) receive the (split) light signals routed over the two separate optical paths 1115C and 1115C'. A benefit of locating these receivers after the switch fabric(s) 1110 is that they can accept a full range of wavelengths of  
10 photons due to dual wave-length division multiplexed (DWDM) light signals. The wide range of wavelengths of light signals over the optical paths in the optical cross-connect switching system 1000 can exist due to DWDM. Being able to cross-connect any light signal to the O/E/O over a range of wavelengths is desirable to provide wavelength conversion/translation in the optical cross-  
15 connect switching system 1000.

Another benefit is that if some negative optical conditions or negative timing parameters exist in the cross connected light signal from the switch fabric, such as low optical power, wrong wavelength, poor spectral quality, overpower, etc. within the cross-connect switching system, it can be isolated by the O/E/O  
20 before being output to the network. The split light signals are converted into two electrical signals by the optical receivers 1128A and 1128B and routed into the multiplexer 1129. The two electrical signals can also be monitored locally to determine which should be selected to generate the output light signal. It can also be forced to switch by means of external communication control, if external  
25 monitoring methods are employed. The multiplexer 1129 electronically selects one of the two electrical signals to be coupled into the optical transmitter 1127 (an E/O converter such as a semiconductor laser). If the two signals being selected from have the same data and protocol, as expected, it is envisioned that the monitored switching between the two within the multiplexer 1129 could be  
30 hitless, i.e. produce no errors on the selected electrical signal. This behavior is very beneficial to bridge and roll applications and those that have Forward-Error-

Correction data encoding schemes. This would also apply to SONET and SONET like data streams as well as those employing a 'wave wrapper' protocol. The optical transmitter 1127 converts the selected electrical signal in the electrical domain into a light signal in the optical domain for transmission out over the output port 1112 of the optical cross-connect switching system 1000. Thus, in the output path 1112 of the I/O port module 1104A'-1104M', an optical-electrical-optical conversion (O/E/O) is performed.

Bridging in this manner provides that if an optical path or a component in the path fails, the other path and components can handle the data flow over the communication channel in the optical cross-connect switching system 1000. A disadvantage to the bridging provided by the different embodiments of the optical cross-connect switching system 1000 of Figures 15 and 16 is that fewer communication channels can be supported because of the redundant optical paths formed in the switch fabrics 1010 and 1110 respectively. One way to alleviate this problem is to use a redundant switch fabric to provide the redundant path.

#### VI. 1:K Protection Scheme for Equipment Redundancy

As previously described above, one technique for providing equipment redundancy is to implement two or more switch fabrics, each receiving a bridged, light signal. A better copy (higher power level) of the bridged, light signals is selected as the output light signal. Alternatively, as shown in Figure 17, if a single optical switch (or switch port) is more likely the cause for failure than the entire switch fabric 1300, then a 1:K protection scheme may be employed.

Herein, for every K switch ports 1310<sub>1</sub>-1310<sub>K</sub>, an additional switch port 1320 of the switch fabric 1300 is designed as a spare port. For this embodiment, "K" is a positive whole number. The particular value for K is based on a design choice and the selected degree of switch reliability for the optical cross-connect switching system. For example, a maximum redundancy is where one or more additional ports are reserved for each switch port. A minimum redundancy is where one additional switch port is reserved for a large number of switch ports.



As further shown in Figure 17, K incoming light signals along input optical paths 1330<sub>1</sub>-1330<sub>K</sub> are bridged by splitters 1340<sub>1</sub>-1340<sub>K</sub> within one or more I/O port modules. Based on an incoming light signal, one outgoing light signal is routed along a primary optical path 1350, represented by optical paths 5 1350<sub>1</sub>-1350<sub>K</sub>, to corresponding switch ports 1310<sub>1</sub>-1310<sub>K</sub> of the switch fabric 1300. The other outgoing light signal is routed along a secondary optical path 1360, represented by optical paths 1360<sub>1</sub>-1360<sub>K</sub>, to a corresponding port of an optical (K:1) switch fabric 1370. The optical switch fabric 1370 includes K switch inputs and one switch output that is coupled to additional switch port 1320 10 via link 1380.

In accordance with the switching architecture described above, in the event that one of the optical switches associated with the primary optical path 1350<sub>1</sub>-1350<sub>K</sub> fails, a decrease in power is sensed from the routed light signal. This decrease in power is used to trigger the change from the switch port 15 1310<sub>1</sub>,...1310<sub>K</sub> associated with the failed optical switch to the additional switch port 1320.

## VII. Test Access Functionality

20 Test access is a function by which a signal flowing through an optical switch can be monitored in a non-intrusive manner through a switch port designated for this purpose. Herein, certain embodiments for performing test access are described, although it is contemplated that other embodiments may be developed in accordance with the spirit of the invention.

25 Referring now to Figure 18, a first exemplary embodiment for providing test access functionality through redundancy is shown. An incoming light signal is bridged by a splitter 1405 at a source I/O port module 1400 to produce a first and second outgoing light signals. The first outgoing light signal is routed to a first switch fabric 1410 via link 1420 while the second outgoing light signal is 30 routed to a second switch fabric 1430 via link 1440. Herein, in one embodiment,

the first switch fabric 1410 is part of a first optical switch core. The second switch fabric 1430 is part of a second optical switch core.

Shown as an illustrative example, the first outgoing light signal is selected by a switch 1460 at a destination I/O port module 1450 to be output. The other  
5 light signal, namely the second outgoing light signal, is routed to a test access port 1470 associated with the second optical switch 1430. Furthermore, an input port on the second optical switch 1430 can also be dedicated to test signal injection for further testing functionality. An O/E monitoring device 1480 may be coupled to the test access port 1470 (as represented in dashed lines) to analyze the incoming  
10 light signal and perhaps the operations of the second optical switch 1430 itself.

Referring to Figure 19, a second exemplary embodiment for providing test access functionality through additional switching is shown. Herein, incoming light signals over input paths  $1510_1$ - $1510_N$  are routed through I/O port modules  $1500_1$ - $1500_N$ . More specifically, the incoming light signals are bridged by  
15 splitters  $1520_1$ - $1520_N$  of the I/O port modules  $1500_1$ - $1500_N$  and one output of each I/O port module  $1500_1$ - $1500_N$  is sent into a (NxN) switch fabric 1530. All other outputs are routed to a unique switch port of a Nx1 switch fabric 1540. The Nx1 switch fabric 1540 features a single output port 1550 being designated as the test access port. An O/E converter and monitoring device may be coupled to the test  
20 access port 1550 to analyze the light signals routed from splitters  $1520_1$ - $1520_N$ . This Nx1 switch fabric 1540 could potentially also be part of the larger switch core.

Referring now to Figures 20A-20G and 21, block diagrams of exemplary embodiments of an optical cross-connect switching system 1000 utilizing a test  
25 access port is illustrated. The optical cross-connect switching system 1000 include I/O port modules  $1604$ - $1604_N$  that provide bridging by using two (optical) switch fabrics (also referred to as optical switch cores) 1610A and 1610B. An incoming signal is split into at least two bridged, light signals with one portion being routed into one switch fabric 1610A with another portion of the  
30 signal being routed into the other switch fabric 1610B. While one switch fabric 1610A acts as the "active" switch fabric, the other switch fabric 1610B acts as a

“redundant” switch fabric. Providing a redundant switch fabric also provides reliability in case there is a problem in control of one of the switch fabrics.

Furthermore, the redundant switch fabric 1610B provides hot swapability in that while one is having its switch fabric or other control systems updated or replaced, the other can continue to provide optical switching. The optical cross-connect switching system 1000 also includes a test port/monitor module 1605 to test and monitor the optical paths through the two switch fabrics 1610A and 1610B in order to detect equipment or facility failures.

More specifically, as shown in Figure 20A, the optical cross-connect switching system 1000 includes the first switch fabric 1610A, the second switch fabric 1610B, and one or more I/O port modules. These I/O port modules provide one or more optical input ports 1601A-1601N and one or more optical output ports 1602A-1602N as shown. The optical cross-connect switching system 1000 can also include one or more different types of I/O port modules such as one or more I/O port modules 1604A-1604N (generally referred to as 1604) and/or one or more I/O port modules 1604A'-1604M' (generally referred to as 1604'). The optical cross-connect switching system 1000 can also include one or more test port/monitor modules 1605.

The I/O port modules 1604A-1604N provide an O/E/O converter (referred to as “O/E/O”) 1607 in their input paths while the I/O port modules 1604A'-1604M' provide an O/E/O 1607' in their output paths. The I/O port modules 1604A-1604N and 1604A'-1604M' each have an optical splitter 1608 and 1608' respectively in their input paths. The I/O port modules 1604A-1604N and 1604A'-1604M' each have an optical switch 1609 and 1609' respectively in their output paths. The O/E/Os 1607 and 1607', optical switches 1609 and 1609', and the optical splitters 1608 and 1608' are optically coupled together within the I/O port modules 1604A-1604N and 1604A'-1604M' as shown and illustrated in Figures 20A and 20B.

In either type of I/O port modules 1604 or 1604', the optical splitter 1608 or 1608' splits the incoming light signal into at least two outgoing light signals. These outgoing light signals are routed over different optical paths, one of which

is routed to the first switch fabric 1610A and the other which is routed to the second switch fabric 1610B. In either type of I/O port modules 1604 or 1604', the optical switch 1609 and 1609' selects a light signal from the two outgoing light signals having the better signal quality over two differing optical paths, one of which is received from the first switch fabric 1610A and the other of which is received from the second switch fabric 1610B. In this manner, should an optical path in one of the two switch fabrics 1610A or 1610B fail for any reason, the optical switch 1609 or 1609' only need select the opposite signal path.

For example, as an illustration, consider the exemplary optical path 1615A in the first switch fabric 1610A and the optical path 1615A' in the second switch fabric 1610B. The splitter 1608 in the I/O port module 1604A splits an incoming light signal into at least two outgoing light signals on optical paths 1621A and 1622A. The light signal on the optical path 1621A is routed into the first switch fabric 1610A and the signal on the optical path 1622A is routed into the second switch fabric 1610B. The switch fabrics 1610A and 1610B route these light signals over exemplary optical paths 1615A and 1615A' respectively.

The optical path 1615A in the switch fabric 1610A is coupled into the optical path 1623N which is coupled into the optical switch 1609 of the I/O port module 1604N. The optical path 1615A' in the switch fabric 1610B is routed to the optical path 1624N, which in turn is routed into the optical switch 1609 of the I/O port module 1604N. In one case, the optical switch 1609 of the I/O port module 1604N selects the light signals over the optical path 1615A so that the first switch fabric 1610A is acting as the active switch fabric.

In another case, the optical switch 1609 of the I/O port module 1604N selects the light signals over the optical path 1615A' so that the second switch fabric 1610B is acting as the active switch fabric. If either optical switch fabric fails generating a gap, the other is automatically selected by the I/O port modules to bridge the gap.

For this illustration, light signals from the I/O port module 1604A are coupled into the I/O port module 1604N such that only one O/E/O 1607 is needed to regenerate the light signals input into the optical cross-connect switching

system 1000. If it is desirable to regenerate light signals into as well as out of the optical cross-connect switching system 1000, light signals from one of the I/O port modules 1604A-1604N can be coupled into one of the I/O port modules 1604A'-1604M' which have an O/E/O 1607' to regenerate the output light signals  
5 in the output path.

Other I/O port modules can be used with more than one switch fabric to provide redundancy. Figures 20B-20G illustrate exemplary embodiments of other combinations of I/O port modules that can be used with the two (optical) switch fabrics 1610A and 1610B.

10 Referring now to Figure 20B, the cross-connect switching system 1000 includes I/O port modules 1104A-1104N, I/O port modules 1104A'-1104M', test port/monitor module 1605, network control module (NCM) 1606, first (optical) switch fabric 1610A, and second (optical) switch fabric 1610B. The elements of I/O port modules 1104A-1104N and I/O port modules 1104A'-1104M' were  
15 previously discussed with reference to Figure 16. The optical cross-connect switching system 1000 provides redundancy but uses differing I/O port modules having different components.

Referring now to Figure 20C, the optical cross-connect switching system 1000 includes I/O port modules 1644A-1644N, I/O port modules 1644A'-  
20 1644M', test port/monitor module 1605, network control module (NCM) 1606, first switch fabric 1610A, and second switch fabric 1610B. I/O port modules 1644A-1644N and I/O port modules 1644A'-1644M' utilize optical switches 1628 and 1628' as opposed to splitters 1608 and 1608' in I/O port modules 1604A-1604N and 1604A-1604M' respectively which were previously described.  
25 Optical switches 1628 and 1628' provide less optical power loss than the splitters 1608 and 1608' so that a stronger light signal can be routed through the switch fabric.

Referring now to Figure 20D, the optical cross-connect switching system 1000 includes I/O port modules 1654A-1654N, I/O port modules 1654A'-  
30 1654M', test port/monitor module 1605, network control module (NCM) 1606, first switch fabric 1610A, and second optical switch fabric 1610B. I/O port

modules 1654A-1654N and I/O port modules 1654A'-1654M' utilize optical switches 1628 and 1628' and optical couplers 1629 and 1629' as opposed to splitters 1608 and 1608' and optical switches 1609 and 1609' in I/O port modules 1604A-1604N and 1604A'-1604M' respectively which were previously described.

- 5 Optical switches 1628 and 1628' provide less optical power loss than the splitters 1608 and 1608'. Optical couplers 1629 and 1629' act similar to a multiplexer and can be passive so that no switching control is required.

Referring now to Figure 20E, the optical cross-connect switching system 1000 includes I/O port modules 1654A-1654M, passive I/O port modules 1653A-1653N, test port/monitor module 1605, network control module (NCM) 1606,  
10 first switch fabric 1610A, and second switch fabric 1610B. I/O port modules 1654A-1654M utilize optical switches 1628 and optical couplers 1629 as opposed to splitters 1608 and optical switches 1609 in I/O port modules 1604A-1604N respectively which were previously described. Each of the passive I/O port  
15 modules 1653A-1653N includes the optical switch 1628 in the input path and the optical coupler 1629 in the output path as shown. Each of the I/O port modules 1653A-1653N does not have an O/E/O in either its input path or its output path. That is, optical cross connect switching providing at least one redundant switch fabric can also use these types of passive I/O port modules to reduce the number  
20 of O/E/Os and lower costs.

Referring now to Figure 20F, alternate combinations of different types of I/O port modules within an optical cross-connect switching system having at least one redundant optical switch fabric is shown. In Figure 20F, the optical cross-connect switching system 1000 includes I/O port modules 1604A'-1604M',  
25 passive I/O port modules 1663A-1663N, test port/monitor module 1605, network control module (NCM) 1606, first switch fabric 1610A, and second switch fabric 1610B. I/O port modules 1604A'-1604M' were previously described with respect to Figure 20A. Each of the passive I/O port modules 1663A-1663N includes an optical splitter 1668 in the input path and an optical switch 1669 in the output path  
30 as shown. Each of the passive I/O port modules 1663A-1663N does not have an O/E/O in either their input path or their output path.

Referring now to Figure 20G, another embodiment of combinations of different types of I/O port modules is illustrated for an optical cross-connect switching system having a redundant (optical) switch fabric. In Figure 20G, the optical cross-connect switching system 1000 includes I/O port modules 1604A'-1604M', one or more I/O port modules 1663 and 1670, test port/monitor module 1605, network control module (NCM) 1606, first switch fabric 1610A, and second switch fabric 1610B. The I/O port modules 1604A'-1604M' were previously described with respect to Figure 20A. The I/O port module 1663 includes an optical splitter 1668 in the input path and an optical switch 1669 in the output path as shown. The I/O port module 1670 provides only a flow through optical path between input and output ports and the switch fabrics 1610A and 1610B. Each of the I/O port modules 1663 and 1670 are deemed "passive" because they do not have an O/E/O in either their input path or their output path.

While other combinations of I/O port modules and (optical) switch fabrics can be formed, it is desirable to provide light signal regeneration by routing a light signal over an optical path through the optical cross-connect switching system so that at least one O/E/O conversion occurs to the light signal to increase the optical power level at the output from what was received at the input. The O/E/O conversion may be used for other reasons as well which were previously described. If it is desirable, a signaling channel previously described between the optical cross connect switch and attached network or client equipment can be used to provide information regarding signal conditions and performance of and around the optical cross-connect switch. The signaling channel is particularly desirable if nothing but passive I/O port modules without O/E/Os are used in channels of the optical cross-connect switch.

The optical cross-connect switching system 1000 having redundant switch fabrics can readily provide self testability. The optical cross-connect switching system 1000 can optionally include a test port/monitor module 1605 in order to test the optical paths through the first and second switch fabrics 1610A and 1610B to perform sophisticated performance monitoring and attach test equipment if needed. One port of either switch fabric 1610A or 1610B can be dedicated as a

test access port. The test port/monitor module 1605 is inserted into the dedicated test access port and monitors one of the split signals to determine if there is a failure in the optical path or not as well as to determine performance measures for the light signal including a bit error rate (BER). Any incoming light signal

5 passing through the optical cross-connect 1000 can be accessed and monitored by switching one of the split signals over to the test access port where the test port/monitor module 1605 is present. The other part of the split signal continues to be routed through the optical cross-connect switching system 1000 unaffected. The test access port and test port/monitor module 1605 allow non-intrusive

10 monitoring of the incoming light signals.

As shown in Figure 21, the test port/monitor module 1705 includes an optical switch 1719 and an optical-to-electrical (O/E) converter 1717. The O/E 1717 couples to a controller (e.g., a NCM 1606) within the optical cross-connect 1000 via link 1711 in order to process the electrical signals from the test

15 port/monitor module 1705 representing the light signal of the tested optical path. The optical switch 1717 selects between monitoring an optical path of the first switch fabric 1610A and an optical path of the second switch fabric 1610B. The switch fabric which is being monitored can be referred to as the "redundant switch fabric", while the switch fabric that is being used to carry data over the

20 communication channel connection is referred to as the "active switch fabric". In Figure 21, the second switch fabric 1610B is being monitored.

The test port selects a port to monitor to determine if a light signal is actually present on the split optical paths and if so, if the optical path carrying the data in the first switch fabric is reliable or has failed. The signals can also be

25 monitored to determine what is the bit error rate through the optical cross-connect switching system 1000. The test port/monitor module 1605 or 1705 steps from path to path to sample the signals on the paths to determine where a failure may occur. The test port/monitor module 1605 or 1705 can use an algorithm such as a round robin algorithm to test each path in sequence. If a faulty path is detected,

30 the test port/monitor module 1605 or 1705 raises an alarm and the information is



sent to a network control module, for further fault isolation and servicing of the failure.

5 The test port/monitor module 1605 or 1705 can also ping-pong from one switch fabric to another in order to alternate the testing process. In Figure 20A, the second optical switch fabric 1610B is being monitored by the optical path 1626 using a first test input port. Referring momentarily to Figure 21, the first switch fabric 1610A is being monitored by the optical path 1625 using a second test input port as opposed to the second switch fabric 1610B to illustrate the ping-pong between switch fabrics 1610A and 1610B. Either of the test port/monitor  
10 module 1605 or 1705 can step from path to path to sample the signals over the optical paths to determine where a failure may occur. If a faulty optical path is detected, an alarm is signaled and it is removed from available paths in the respective switch fabric until its repaired or the redundant switch fabric is selected to replace the failing path.

15 Referring now to Figures 20A and 21, the test port/monitor module 1605 illustrated in Figure 20A monitors incoming light signals for either switch fabric. The test port/monitor module 1705 illustrated in Figure 21 can monitor incoming light signals from either switch fabric 1610A or 1610B as well as generate its own optical test signal to actively self-test optical paths through the either switch  
20 fabric. In addition to the O/E 1717 and the optical switch 1719, the test port/monitor module 1705 includes an electrical-to-optical (E/O) converter 1718 (e.g., a semiconductor laser) to generate a test light signal which is controlled to actively test optical paths through the first and second optical fabrics 1610A and 1610B. The test port/monitor modules 1605 or 1705 can be used in any  
25 configuration of an optical cross-connect switching system including the single and dual switch fabric embodiments disclosed herein.

VIII. Detailed Overview of Performance Monitoring and Topology Discovery for the Cross-Connect Switching System

Referring now to Figure 22, an exemplary embodiment for performance  
5 monitoring and topology discovery utilizing a test access port is shown. Incoming light signals are routed over input paths 1810<sub>1</sub>-1810<sub>N</sub> to I/O ports associated with I/O port modules 1800<sub>1</sub>-1800<sub>N</sub> of the optical cross-connect switching system 1000. Upon receipt, the incoming light signals undergo a bridge operation by splitters 1820<sub>1</sub>-1820<sub>N</sub>. Each splitter 1820<sub>1</sub>, ..., 1820<sub>N</sub> produces one bridged light  
10 signal to an optical switch core 1830 and another bridged light signal to an optical switch 1840. The optical switch 1840 includes N input ports and a single output port 1850 that is designated as the test access port. For example, the optical switch 1840 may be any Nx1 switching device or an Nx1 optical switch core with a single I/O port 1850 as the test access port.

15 An O/E converter and monitoring device 1860 (e.g., a test port/monitor module) may be coupled to the test access port 1850 to analyze light signals routed from any of the splitters 1820<sub>1</sub>-1820<sub>N</sub>. For example, under normal operations, outgoing light signals are sent through the optical switch core 1830 and, at the optical switch 1840, each input I/O port is switched periodically to  
20 route its input light signal to the test access port 1850 for monitoring purposes. So, a single O/E converter and monitoring device 1860 can cycle among all the I/O ports and periodically monitor each one sequentially or randomly. The technique can be extended to support more than one test access port and multiple O/E converter and monitoring devices that cycle through the signal passing  
25 through the optical switch 1840.

The same technique can also be used for topology discovery. For example, each light signal passing through the optical cross-connect switching system 1000 is provisioned with an identifier (or a path trace). In particular, the light signal can be provisioned with an identifier by method of inserting a known  
30 byte or series of bytes in the light signal data stream. This identifier is provisioned in external equipment, e.g., the source of the data. It can also be

encoded by low frequency modulation (sometimes referred to as "pilot tones") that ride on top of generic light paths (protocol of the data is not important in this case). This can be done by various methods, not excluding the optical cross-connect switching system itself. The optical cross-connect switching system can discover identifier information during monitoring by the servo module for instance. Once the information is read and discovered, the optical cross-connect switching system can report connectivity information for a portion of an optical network, commonly called topology discovery. Constant and or periodic monitoring for this type of information would constitute topology tracking.

Detected using the monitoring scheme described above, the path trace can be used to enable the system to identify a set of connections within the network and track these connections.

IX. Detailed Overview of the Bridging Technique for the Optical Cross-Connect Switching System

Referring now to Figures 23-27, exemplary embodiments of the bridging technique for redirecting signals to prevent against disruption of the optical path due to link or equipment failures is shown.

As shown in Figure 23, a first exemplary embodiment of a low-loss bridging technique utilized by a first I/O port module 1900 is shown. In particular, a port 1905 of the I/O port module 1900 receives a light signal over link 1910 and subsequently routes the light signal to a splitter 1920. Herein, the splitter 1920 effectively performs a bridging operation to produce two bridged, outgoing light signals. Under normal operating conditions, a first outgoing light signal is associated with a substantial percentage of the power of the incoming light signal routed over link 1910. At the same time, a second outgoing light signal has a power level that is less than the first outgoing light signal but sufficient enough so that it can be monitored non-intrusively. For example, the splitter 1920 may split a light signal where the first outgoing light signal is associated with ninety percent (90%) of the power while the second outgoing light

signal is associated with ten percent (10%) of the power. Of course, any disparate power levels may be used such as 80/20, 75/25 and the like.

All outgoing light signals are subsequently passed to a switch 1930 which routes the outgoing light signals over links 1940 and 1945 to different groups of  
5 optical switch cores 1950 and 1955. The optical switch cores 1950 and 1955 (e.g., a pair of micro-machine mirrors, etc.) route the first outgoing light signal over link 1960 to an optical switch 1970 within a second I/O port module 1980 while the second outgoing light signal is routed over link 1965 to the optical switch 1970. The optical switch 1970 is configured to select one of the outgoing  
10 light signals received over links 1960 and 1965 based on any number of light signal quality parameters. The non-selected outgoing light signal may be monitored non-intrusively for test access purposes via a test access port as described above.

Referring now to Figure 24, upon detection of a failure of the optical  
15 switch core 1950, the switch 1930 is configured to re-route the first outgoing light signal over link 1945 and the second outgoing light signal over link 1940, respectively. This allows the first outgoing light signal to be routed to the optical switch 1970 via the second optical switch core 1955 that is fully operational.

Alternatively, as shown in Figures 25 and 26, it is contemplated that a  
20 two-state 1x2 switch 1990 may be utilized in lieu of the splitter 1920 and switch 1930 combination of Figures 23 and 24. Under normal operations, the switch 1990 may be configured to route an outgoing signal corresponding to a high percentage (e.g., P%, where  $P > 50$ ) of power from the incoming light signal to the first optical switch core 1950. A lower percentage (e.g.,  $100 - P$  %) of power from  
25 the incoming light signal is routed to the second optical switch core 1955. Upon detection of a failure of the first optical switch core 1950, the switch 1990 is configured to re-route the first outgoing light signal over link 1945 and the second outgoing light signal over link 1940. This allows the first outgoing light signal to be routed to the optical switch 1970 via the second optical switch core 1955 that is  
30 fully operational.

Alternatively, as shown in Figure 27, it is contemplated that a polarization beam splitter 1995 may be utilized in lieu of the 1 x 2 switch of Figures 25 and 26. Under normal operations, the beam splitter 1995 splits an input light signal into two resultant light signals, a first resultant light signal having a first  
5 orthogonal state of polarization (e.g., horizontal) and a second resultant light signal having a second orthogonal state of polarization (e.g., vertical).

For example, the first orthogonal state of polarization is associated with a higher level of power than the second orthogonal state of polarization. Upon detection of a failure of the first optical switch core 1950, the beam splitter 1995  
10 is configured to re-route the first resultant light signal having a first orthogonal state of polarization over link 1945 and the second outgoing light signal having a second orthogonal state of polarization over link 1940. This allows the first outgoing light signal to be routed to the optical switch 1970 via the second optical switch core 1955 that is fully operational.

15 While certain exemplary embodiments have been described and shown in the accompanying drawings, it is to be understood that such embodiments are merely illustrative of and not restrictive on the broad invention, and that this invention not be limited to the specific constructions and arrangements shown and described, since various other modifications may occur to those ordinarily skilled  
20 in the art. For example, the present invention has been described in detail using an optical cross-connect switching system. However, the present invention may be implemented into other optical network equipment that accept optical data signals including an optical bridge, an optical router, an optical hub, an optical node, an optical concentrator, or other networking equipment accepting a data  
25 signal embodied in a light signal. Additionally, it is possible to implement the present invention or some of its features in hardware, firmware, software or a combination thereof where the software is provided in a processor readable storage medium such as a magnetic, optical, or semiconductor storage medium.

CLAIMS

What is claimed is:

- 1           1.       A method comprising:  
2           receiving an incoming light signal having a predetermined power level;  
3       and  
4           performing a bridging operation by splitting the incoming light signal into  
5       at least a first outgoing light signal routed over a first optical data path and a  
6       second outgoing light signal routed over a second optical data path, the second  
7       outgoing light signal to monitor for disruption of the first optical data path.
- 1           2.       The method of claim 1, wherein the first outgoing light signal and  
2       the second outgoing light signal have a collective power level substantially equal  
3       to the predetermined power level.
- 1           3.       The method of claim 2, wherein the collective power level of the  
2       first outgoing light signal and the second outgoing light signal is equal to the  
3       predetermined power level minus a power loss caused by the splitting of the  
4       incoming light signal.
- 1           4.       The method of claim 1, wherein the first outgoing light signal  
2       having a power level substantially greater than a power level of the second  
3       outgoing light signal.
- 1           5.       The method of claim 4 further comprising:  
2           providing the second outgoing light signal to a multiple input optical  
3       switch; and  
4           selecting outputting a signal input into the multiple input optical switch for  
5       analysis by an optical-to-electrical conversion and monitoring device.

1           6.     The method of claim 5 further comprising:  
2           selecting the second outgoing light signal for output from an optical switch  
3     of a destination I/O port module when the first optical path is disrupted.

1           7.     An input/output (I/O) port module comprising:  
2           a substrate; and  
3           a splitter mounted to the substrate, the splitter to receive an incoming light  
4     signal, produce a first bridged light signal and a second bridged light signal as a  
5     redundant light signal in order to increase reliability of information transmissions  
6     in an optical domain.

1           8.     The I/O port module of claim 7, wherein the substrate is a printed  
2     circuit board including a first interface to receive the incoming light signal over an  
3     optical fiber link.

1           9.     The I/O port module of claim 7, wherein the first bridged light  
2     signal and the second bridged light signal produced by the splitter have  
3     substantially equal power levels.

1           10.    The I/O port module of claim 7, wherein the first bridged light  
2     signal and the second bridged light signal produced by the splitter have  
3     substantially disproportionate power levels.

1           11.    The I/O port module of claim 7 further comprising a first tap  
2     coupler coupled to the splitter, the first tap coupler to separate the first bridged  
3     light signal into a first outgoing light signal and a first optical tap signal for use in  
4     monitoring a power level of the first outgoing light signal.

1           12.    The I/O port module of claim 11, wherein the first outgoing light

2 signal and the first optical tap signal produced by the first tap coupler have  
3 substantially disproportionate power levels.

1 13. The I/O port module of claim 11 further comprising a second tap  
2 coupler coupled to the splitter, the second tap coupler to separate the second  
3 bridged light signal into a second outgoing light signal and a second optical tap  
4 signal for use in monitoring a power level of the second outgoing light signal.

1 14. The I/O port module of claim 8 further comprising an optical  
2 switch to select one of the at least two light signals received over the second  
3 interface.

1 15. The I/O port module of claim 14 further comprising an optical-to-  
2 electrical converter to convert the one of the at least two light signals from an  
3 optical domain to an electrical domain for signal analysis.

1 16. The I/O port module of claim 15 further comprising an electrical-  
2 to-optical converter for injecting a test signal to actively test an optical path  
3 through a remotely located switch fabric.

1 17. A scalable optical cross-connect switching system, comprising:  
2 a switch fabric;  
3 a first input/output (I/O) port module including (i) a splitter to receive an  
4 incoming light signal and produce a first and second bridged light signals from the  
5 incoming light signal, (ii) a first tap coupler to receive the first bridged light signal  
6 to produce a first optical tap signal and a first outgoing light signal and (iii) a  
7 second tap coupler to receive the second bridged light signal to produce a second  
8 optical tap signal and a second outgoing light signal; and  
9 a second I/O port module including an optical switch to receive the first  
10 and second outgoing light signals and to select one of the first and second



11 outgoing light signals for output from the second I/O port module.

1 18. The optical cross-connect switching system of claim 17 further  
2 comprising:

3 a first optical link coupled to the first I/O port module, the first optical link  
4 to propagate the incoming light signal; and

5 a second optical link coupled to the second I/O port module, the second  
6 optical link to propagate the selected one of the first and second outgoing light  
7 signals.

1 19. The optical cross-connect switching system of claim 17, wherein  
2 the first optical tap signal and the first outgoing light signal have substantially  
3 equal power levels.

1 20. The optical cross-connect switching system of claim 19, wherein  
2 the second optical tap signal and the second outgoing light signal have  
3 substantially equal power levels.

1 21. The optical cross-connect switching system of claim 17, wherein  
2 the first optical tap signal and the first outgoing light signal have substantially  
3 disproportionate power levels.

1 22. The optical cross-connect switching system of claim 17, wherein  
2 the switch fabric includes an optical switch core.

1 23. The optical cross-connect switching system of claim 17 further  
2 comprising at least one additional I/O port module where the first I/O port module  
3 and the at least one additional I/O port module collectively are K I/O port  
4 modules, where K is greater than or equal to two.

1           24.     The optical cross-connect switching system of claim 23, wherein  
2     the switch fabric comprises  
3           a first optical switch core to receive K first outgoing signals from the K  
4     I/O port modules and a switch port; and  
5           a second optical switch core including K switch inputs and one switch  
6     output to communicate information to the switch port of the first optical switch  
7     core.

1           25.     The optical cross-connect switching system of claim 17, wherein  
2     the switch fabric includes  
3           a first switch fabric to receive the first outgoing light signal; and  
4           a second switch fabric to receive the second outgoing light signal for  
5     routing to the optical switch of the second I/O port module and a switch port  
6     dedicated for injection of a test signal to be read from a test access port of the  
7     second switch fabric.

1           26.     The optical cross-connect switching system of claim 23, wherein  
2     the switch fabric comprises  
3           an optical switch core to receive K first outgoing signals from the K I/O  
4     port modules; and  
5           a Kx1 optical switch core including K switch inputs and one switch output  
6     to communicate information to an optical-to-electrical converter and monitoring  
7     device.

1           27.     A scalable optical cross-connect switching system, comprising:  
2     a first optical switch core;  
3     a second optical switch core; and  
4     a first input/output (I/O) port module including (i) at least one splitter to  
5     receive an incoming light signal and produce a first and second outgoing light

6 signals from the incoming light signal, and (ii) a switching device to receive the  
7 first and second outgoing light signals and to route the first outgoing light signal  
8 to the first optical switch core and the second outgoing light signal to the second  
9 optical switch core when the first optical switch core is fully operational; and  
10 a second I/O port module including an optical switch to receive the first  
11 and second outgoing light signals and to select the first outgoing light signal for  
12 output when the optical switch core is fully operational.

1 28. The optical cross-connect switching system of claim 27, wherein  
2 the second outgoing light signal is routed from a test access port of the second  
3 optical switch core during normal operation.

1 29. The optical cross-connect switching system of claim 27, wherein  
2 the optical switch of the second I/O port module selects the second outgoing light  
3 signal for output when the first optical switch core is non-operational.

1 30. The optical cross-connect switching system of claim 29, wherein  
2 the first outgoing light signal is routed from a test access port of the second  
3 optical switch core when the first optical switch core is non-operational.

1 31. The optical cross-connect switching system of claim 27, wherein  
2 the switching device is an optical switch.

1 32. The optical cross-connect switching system of claim 27, wherein  
2 the switching device is a beam splitter.

1 33. A scalable optical cross-connect switching system, comprising:  
2 a switch fabric including a first optical switch core and a second optical  
3 switch core;  
4 a first input/output (I/O) port module coupled to the first optical switch

5 core and the second optical switch core, the I/O port module including a switch to  
6 (i) receive an incoming light signal, (ii) split then incoming light signal into a first  
7 light signal and a second light signal and (iii) route the first light signal via the  
8 first optical switch core along a first optical path and the second light signal via  
9 the second optical switch core along a second optical path, the first light signal  
10 having a power level greater than the second light signal; and  
11 a second I/O port module including an optical switch to receive the first  
12 and second outgoing light signals and to select the first outgoing light signal for  
13 output from the second I/O port module.

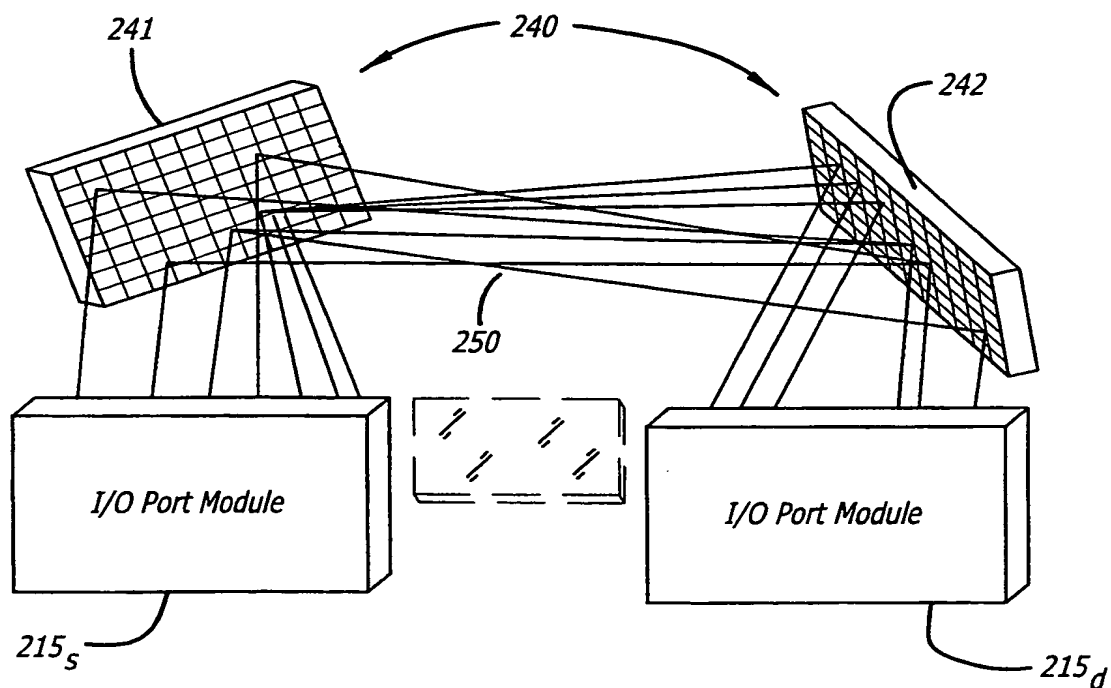
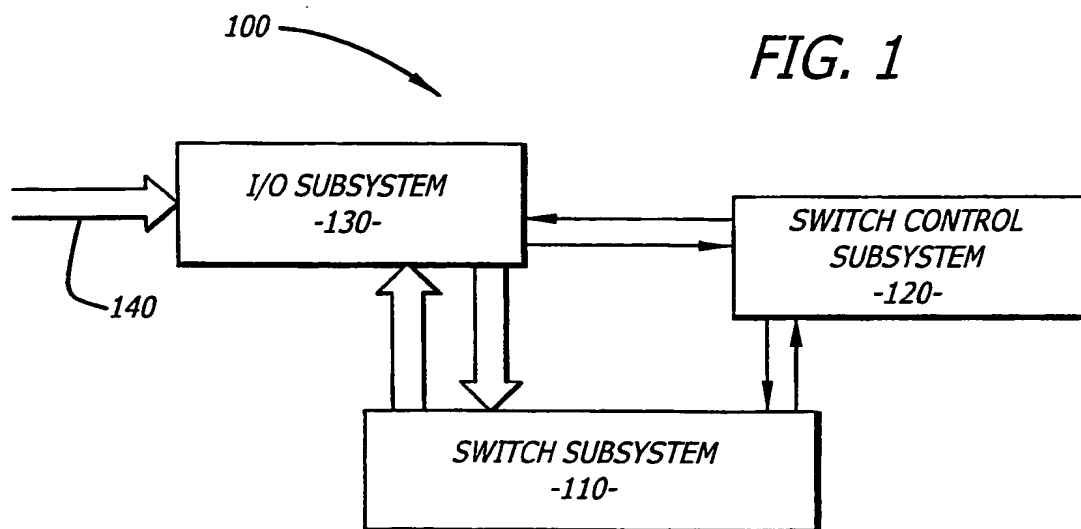
1 34. The optical cross-connect switching system of claim 33, wherein  
2 the second outgoing light signal is routed from a test access port of the second  
3 optical switch core.

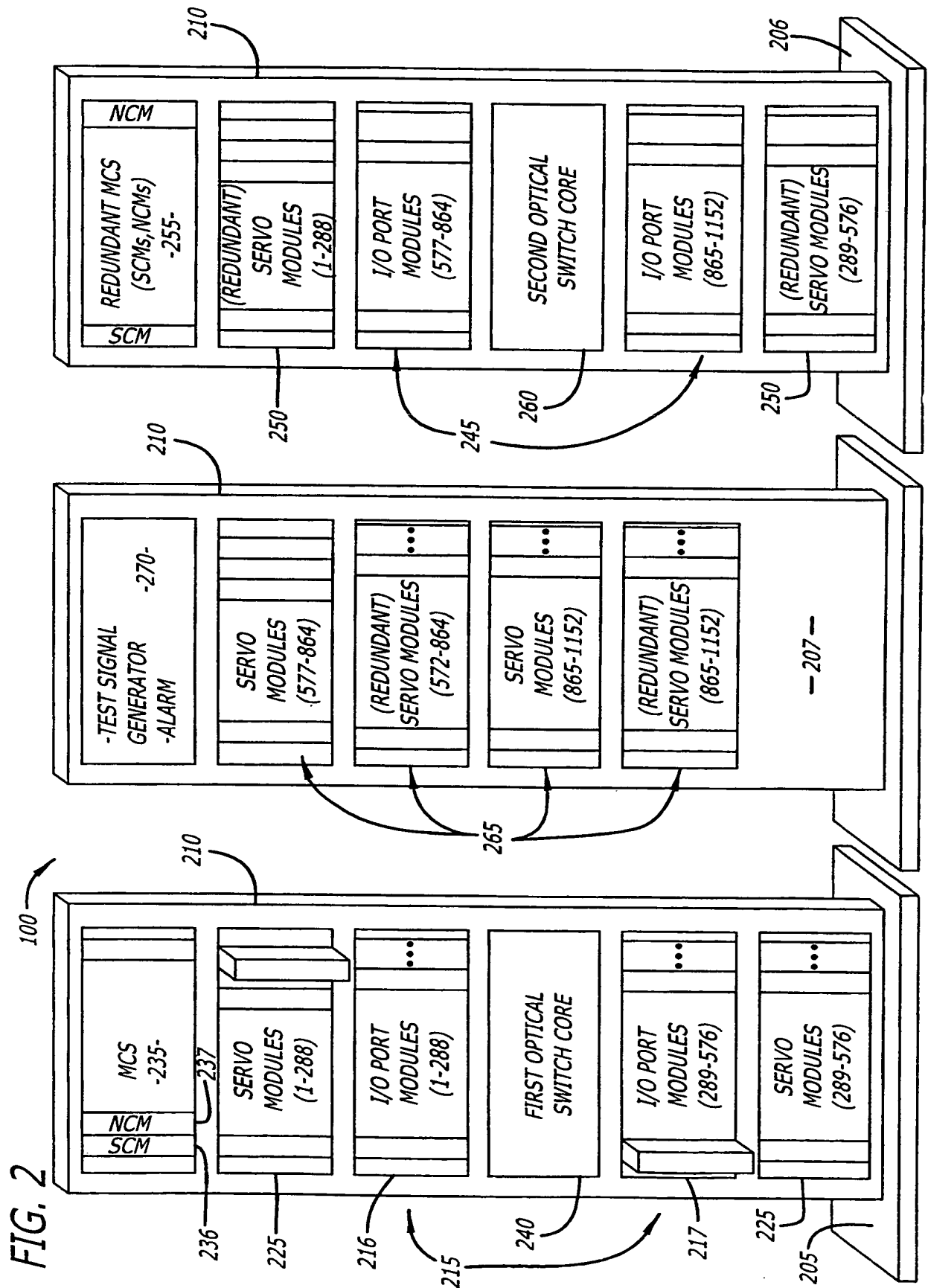
1 35. The optical cross-connect switching system of claim 33, wherein  
2 the optical switch of the second I/O port module selects the second outgoing light  
3 signal for output when the first optical path is disrupted.

1 36. The optical cross-connect switching system of claim 35, wherein  
2 the first outgoing light signal is routed from a test access port of the second  
3 optical switch core when the first optical switch core is non-operational.

1 37. The optical cross-connect switching system of claim 33, wherein  
2 the first outgoing light and the second outgoing light signal have substantially  
3 equal power levels.

1 38. The optical cross-connect switching system of claim 33, wherein  
2 the first outgoing light signal and the second outgoing light signal have  
3 substantially disproportionate power levels.

**FIG. 3**



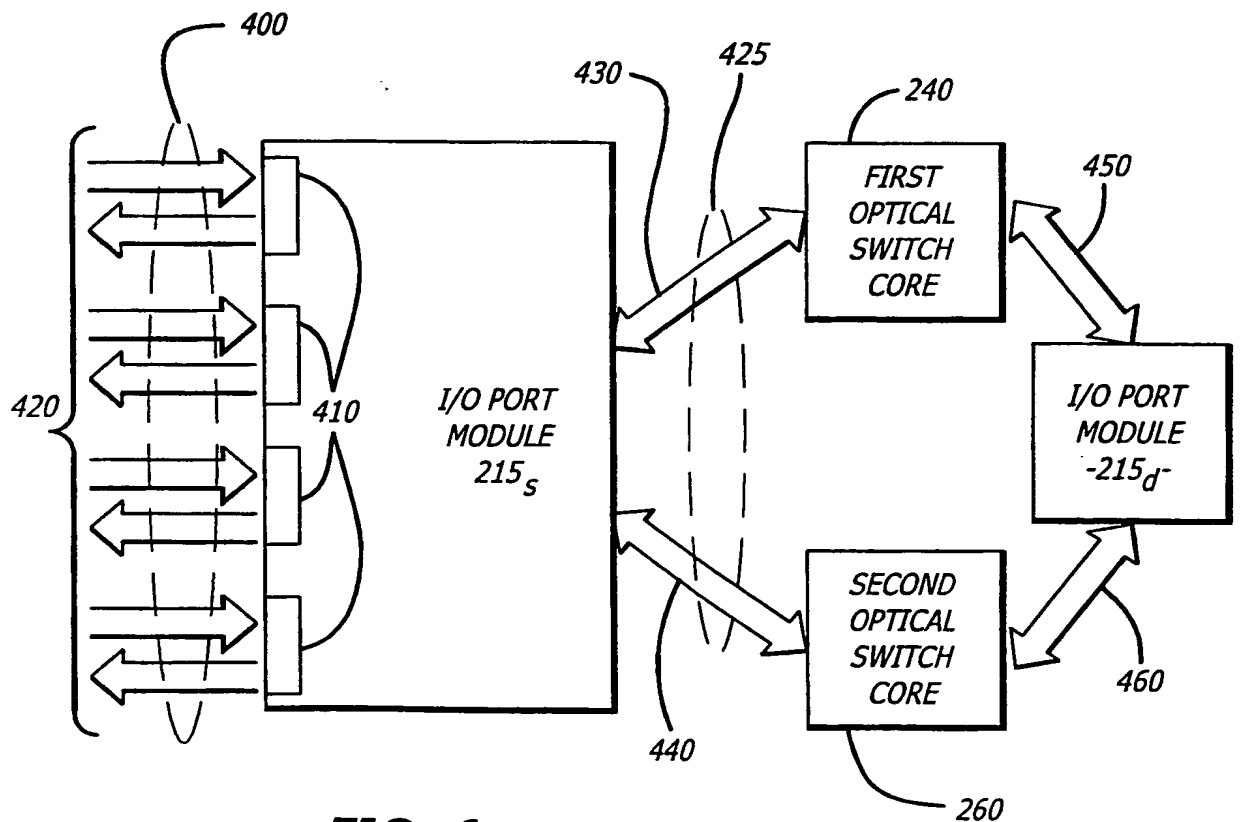
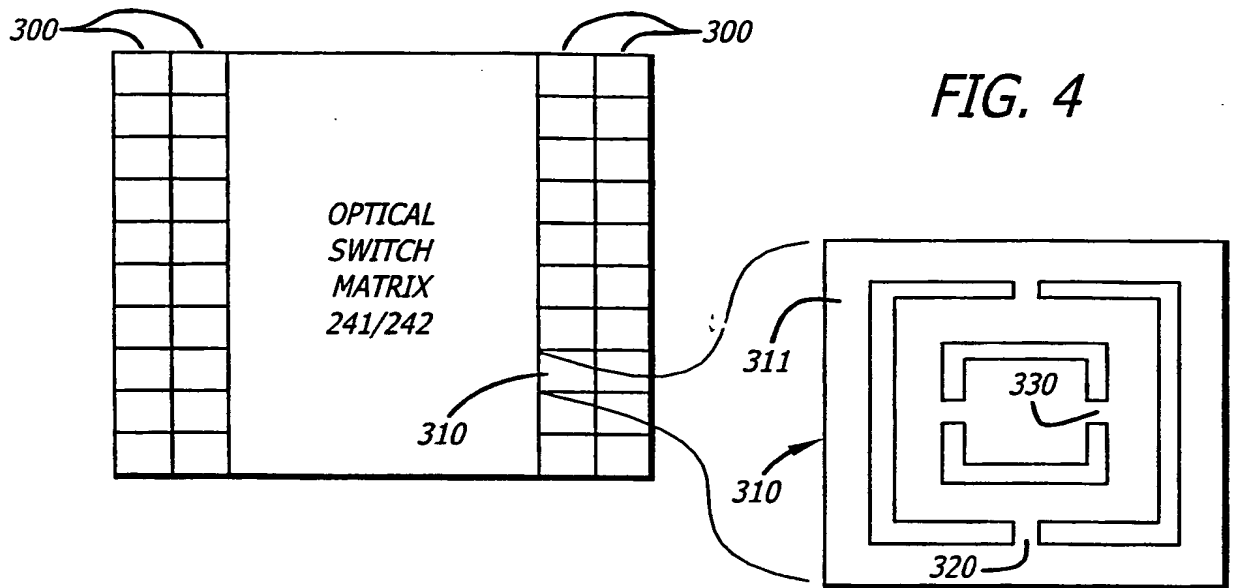
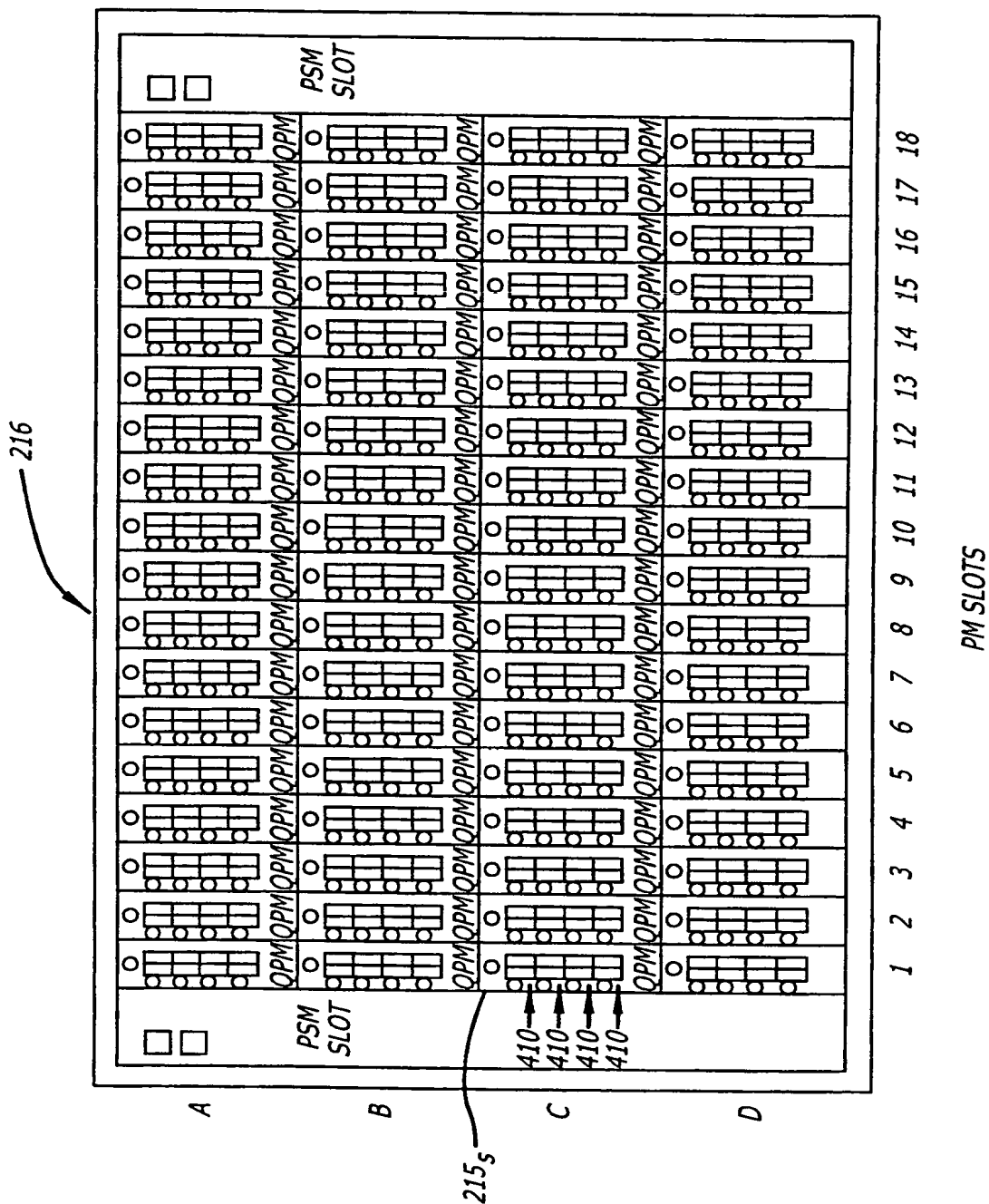


FIG. 6





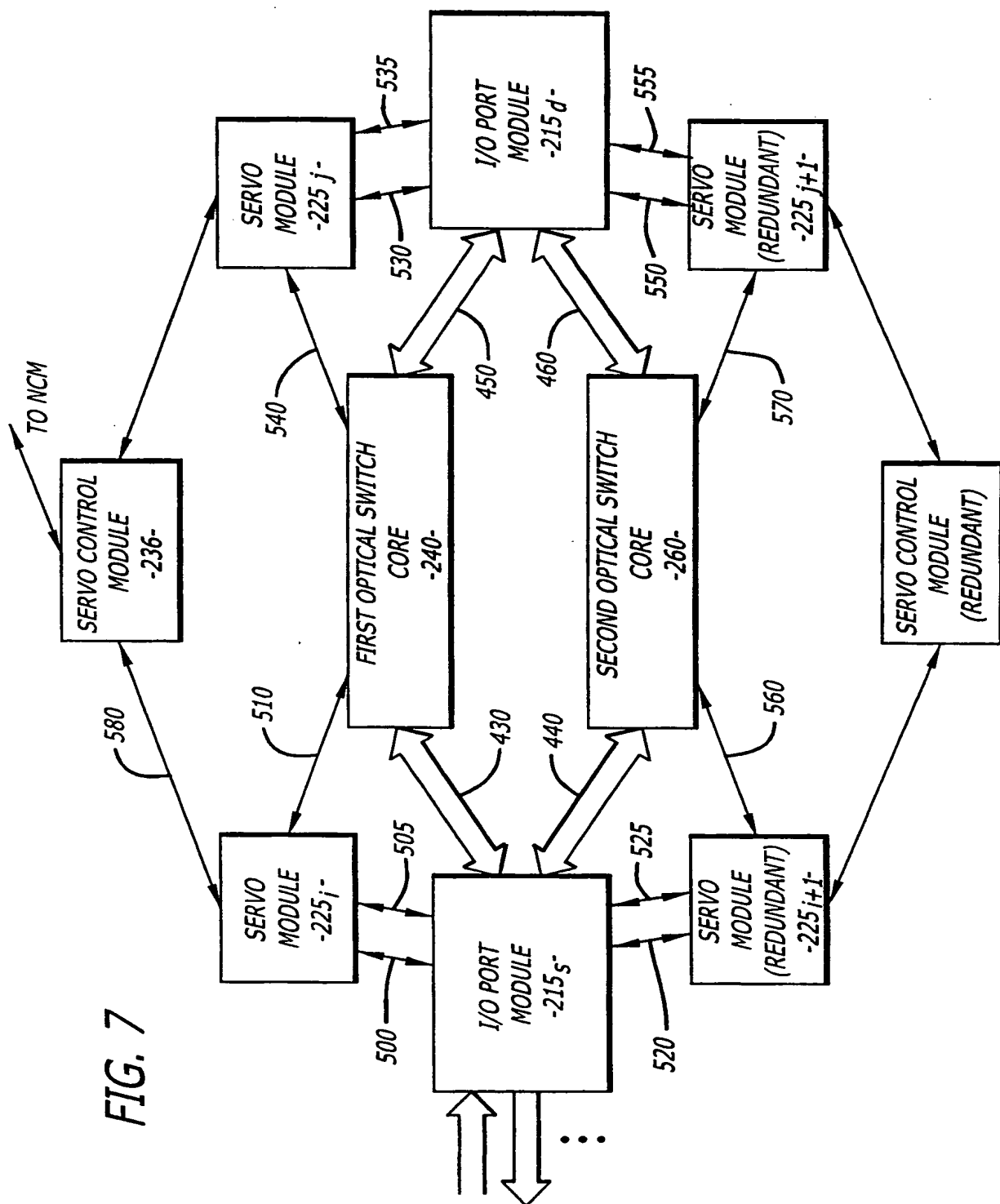


FIG. 7

FIG. 8

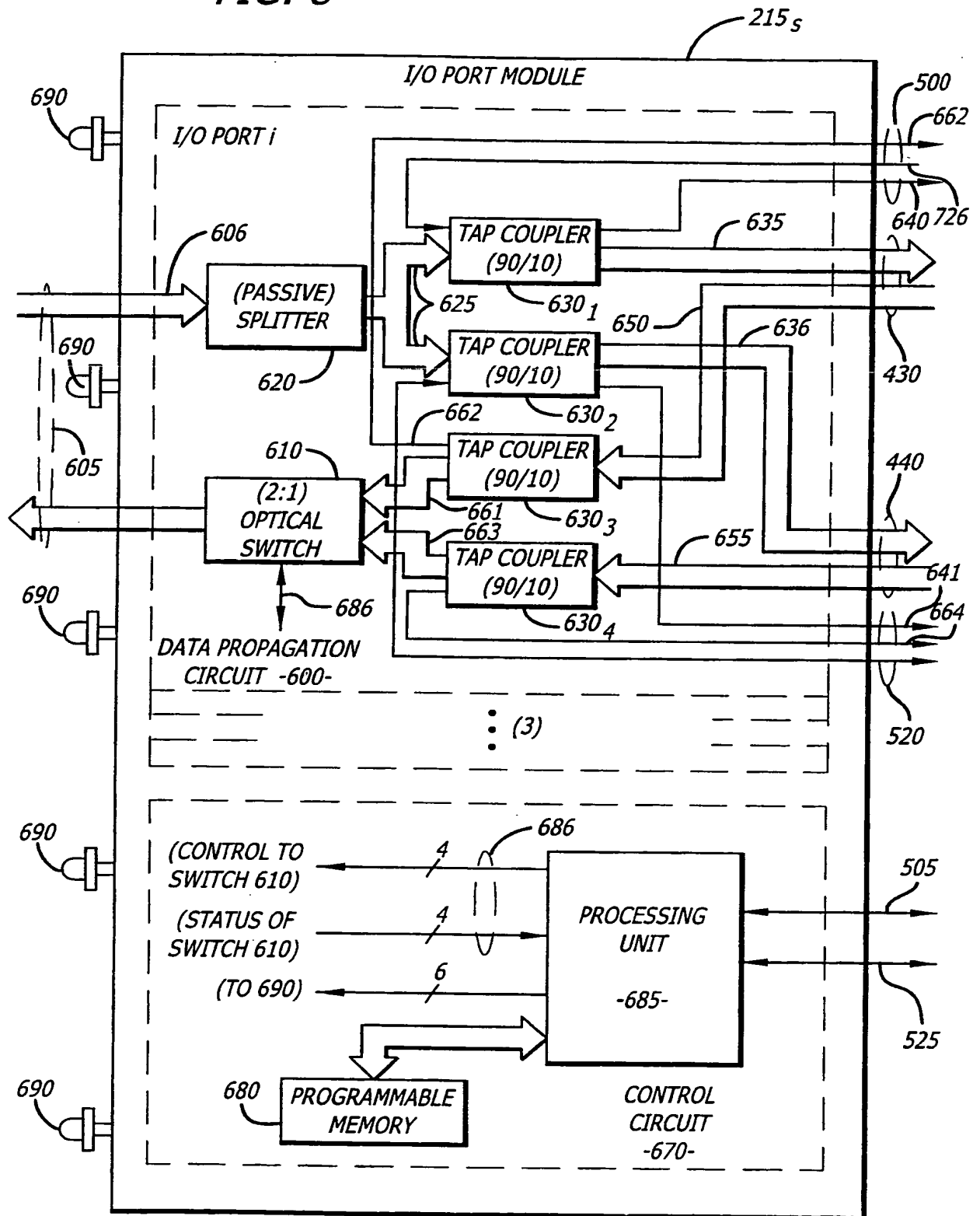
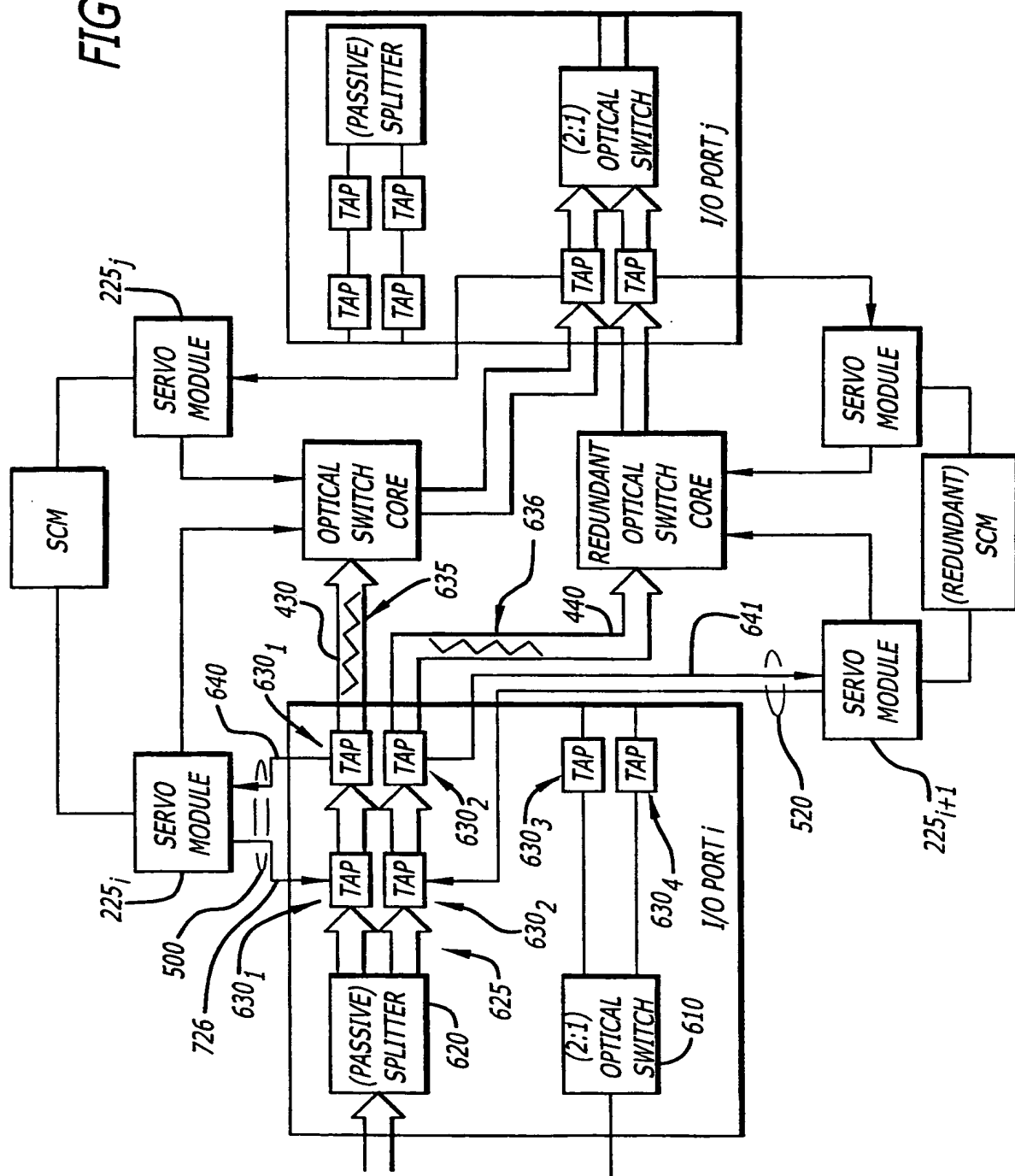


FIG. 9



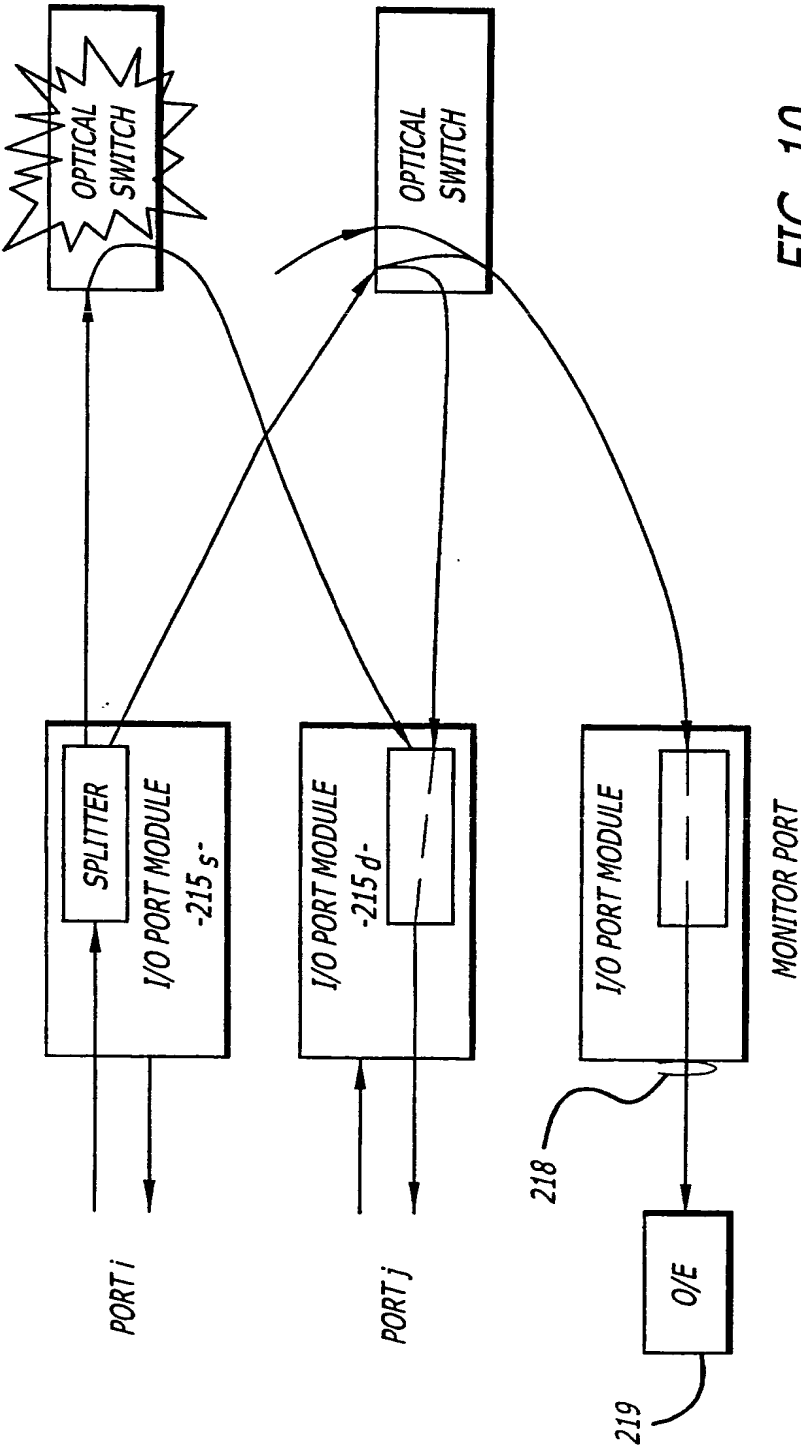


FIG. 10

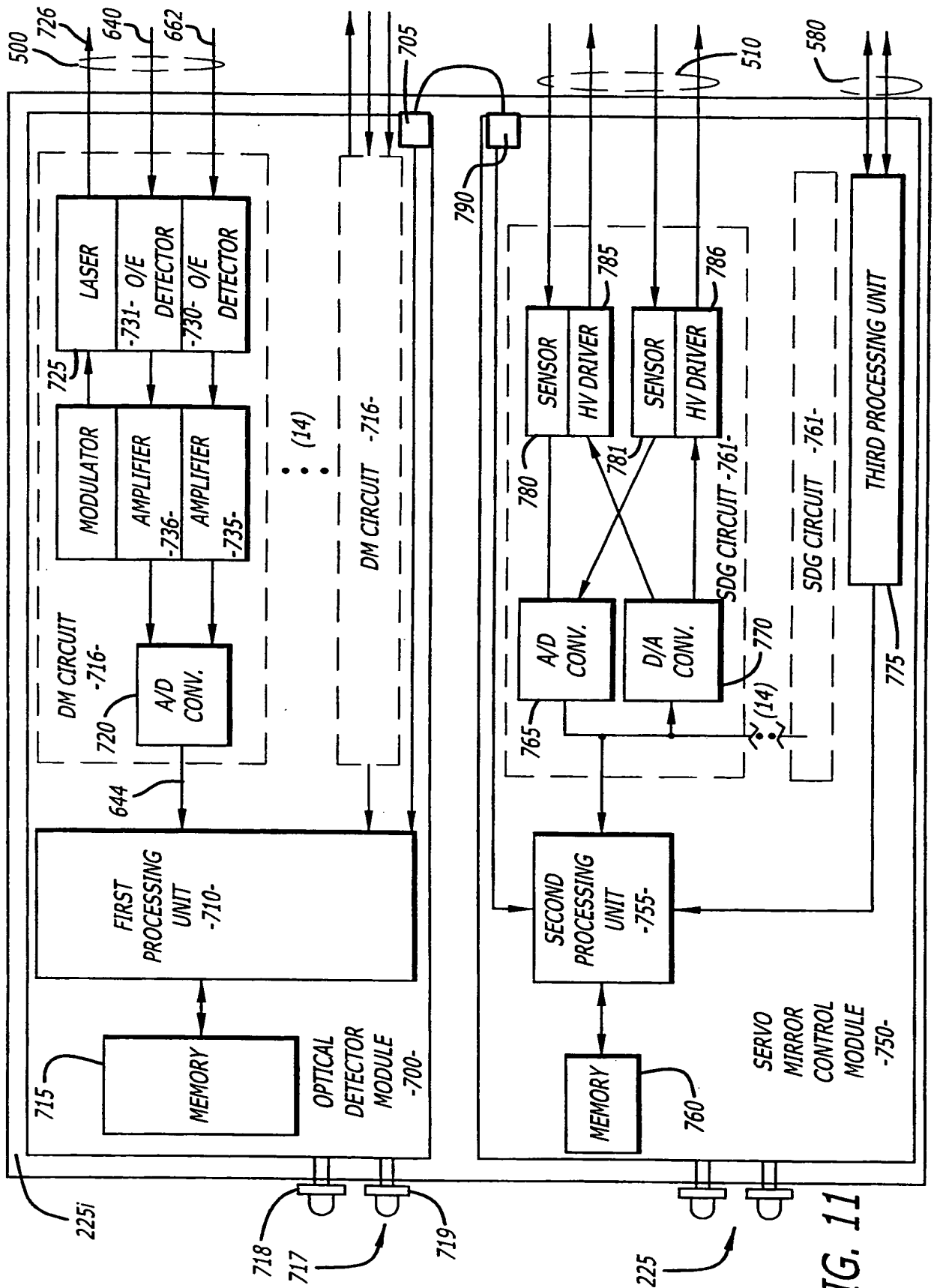


FIG. 11

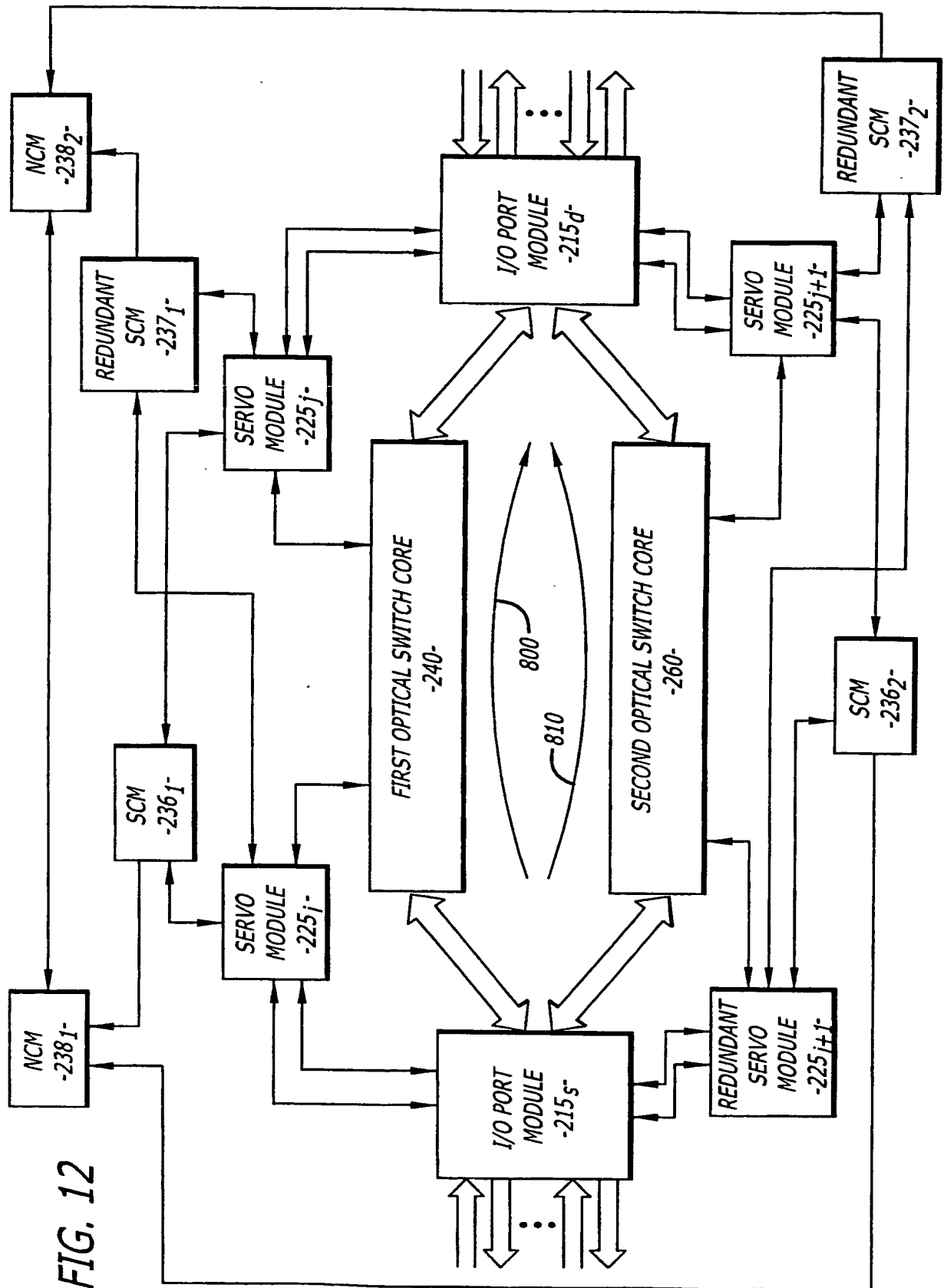


FIG. 12

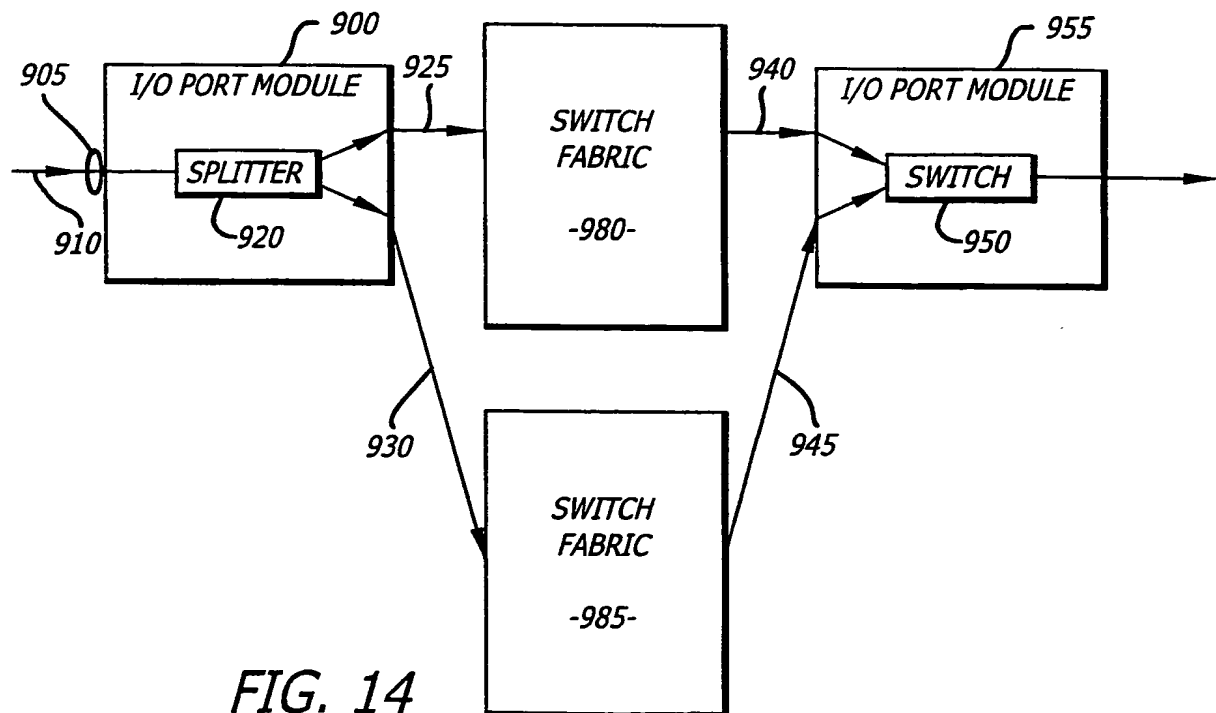
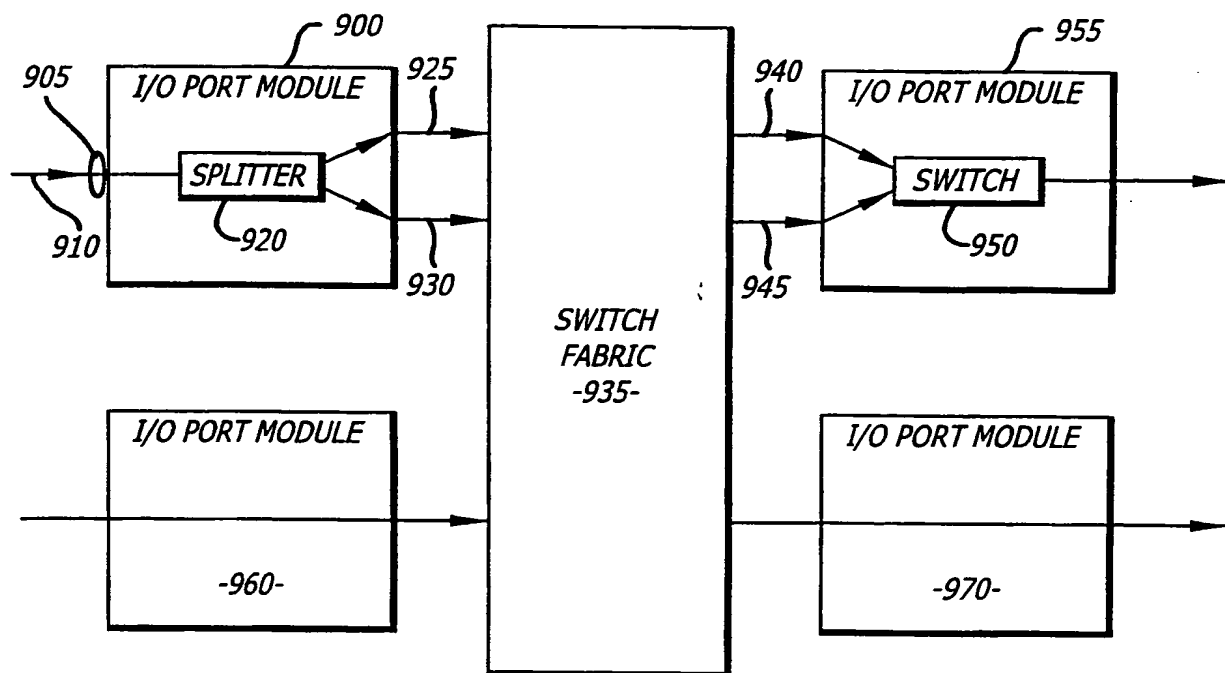


FIG. 15

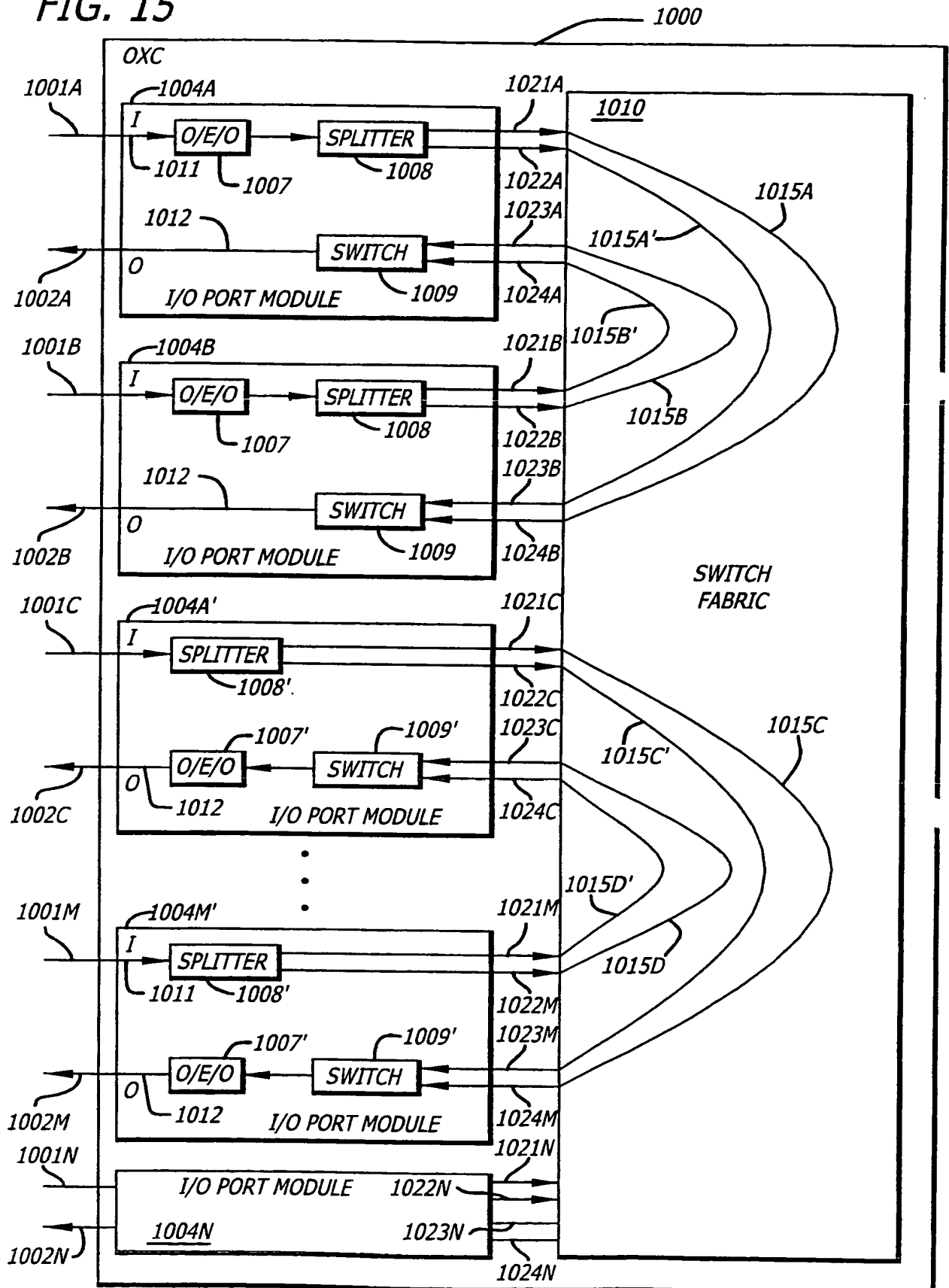
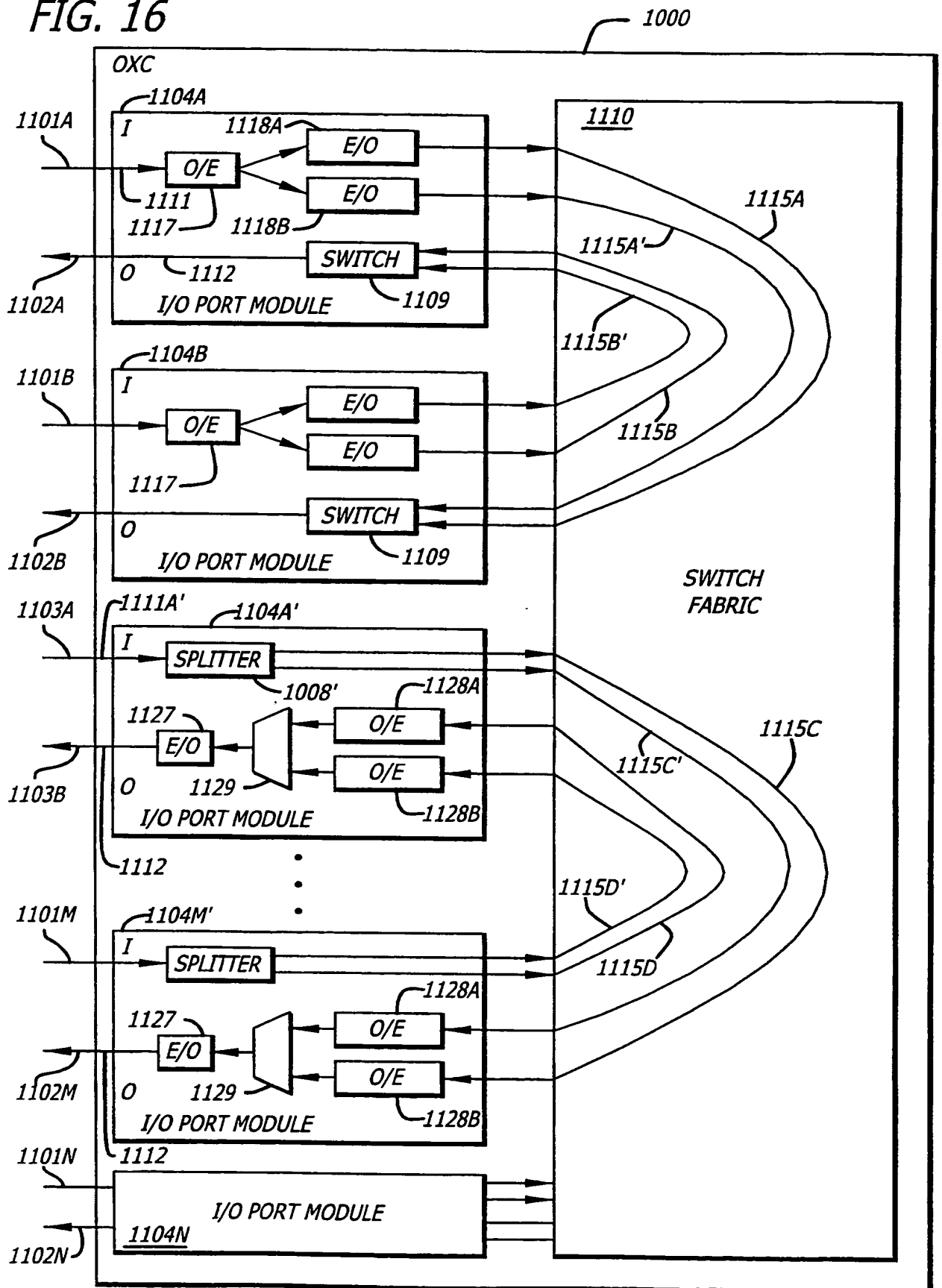
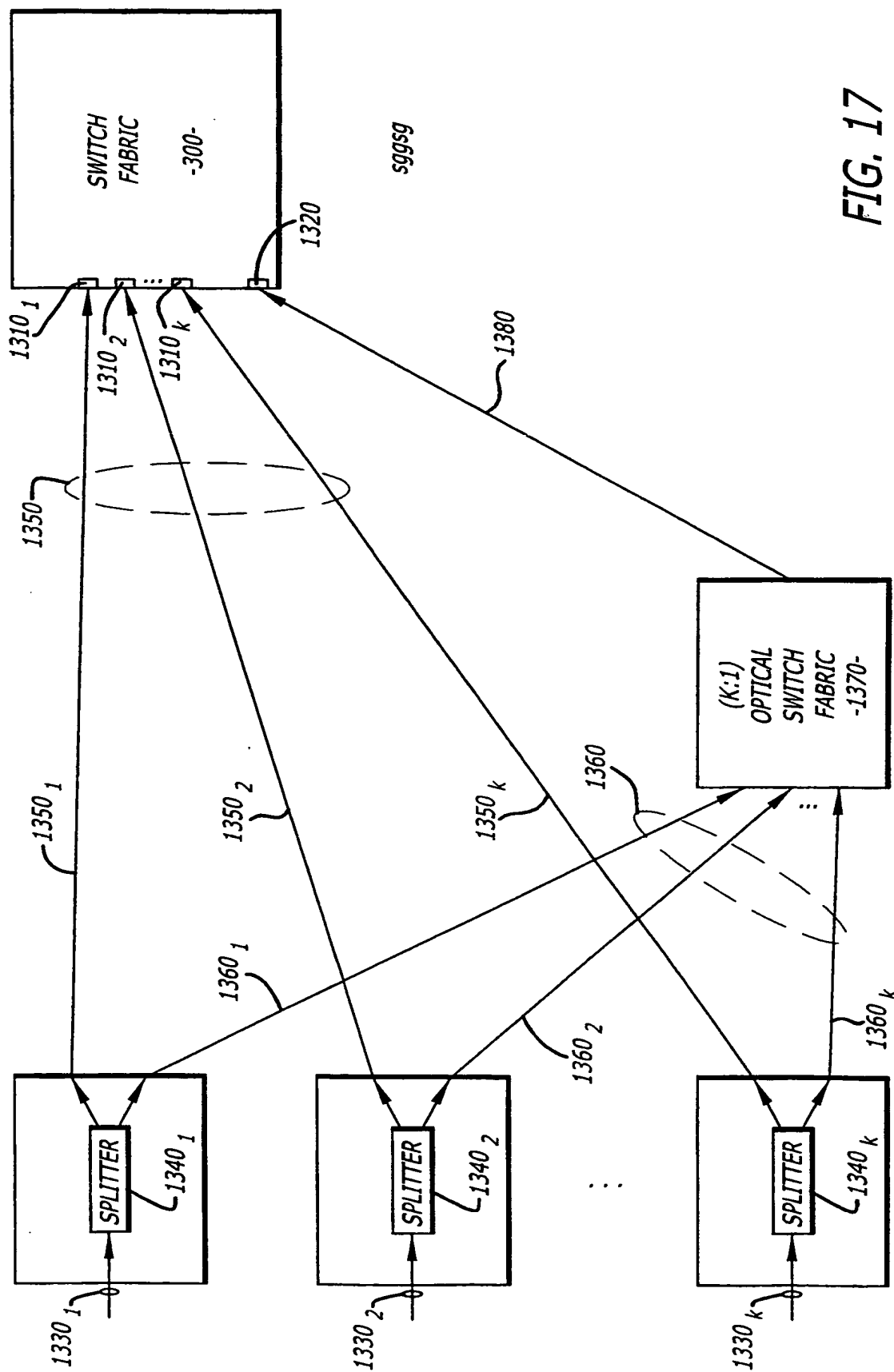




FIG. 16





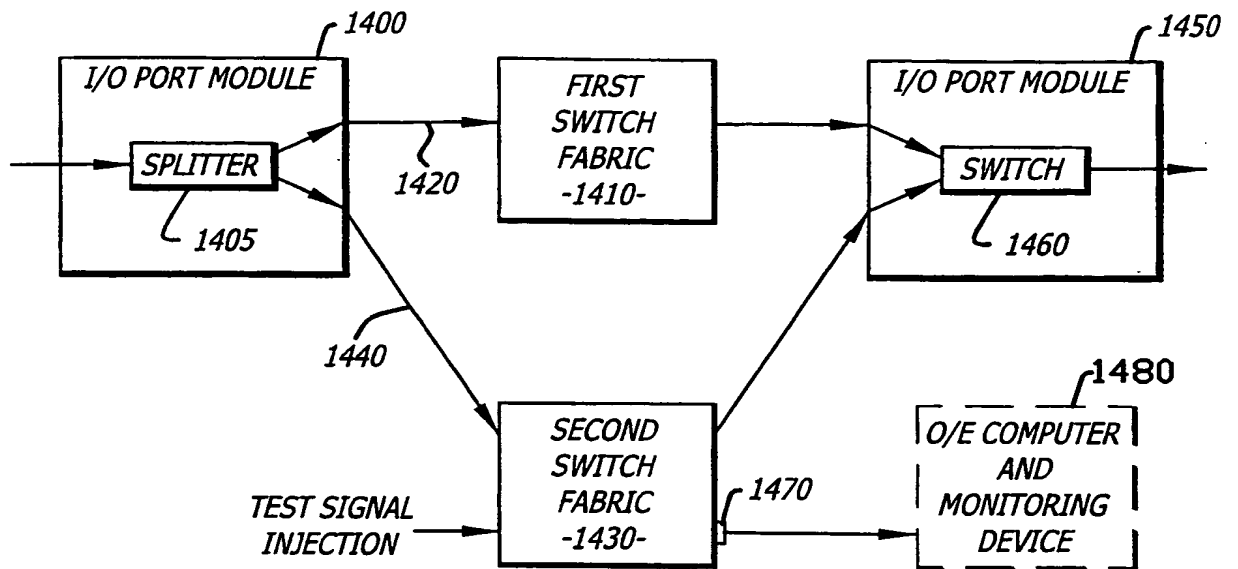


FIG. 18

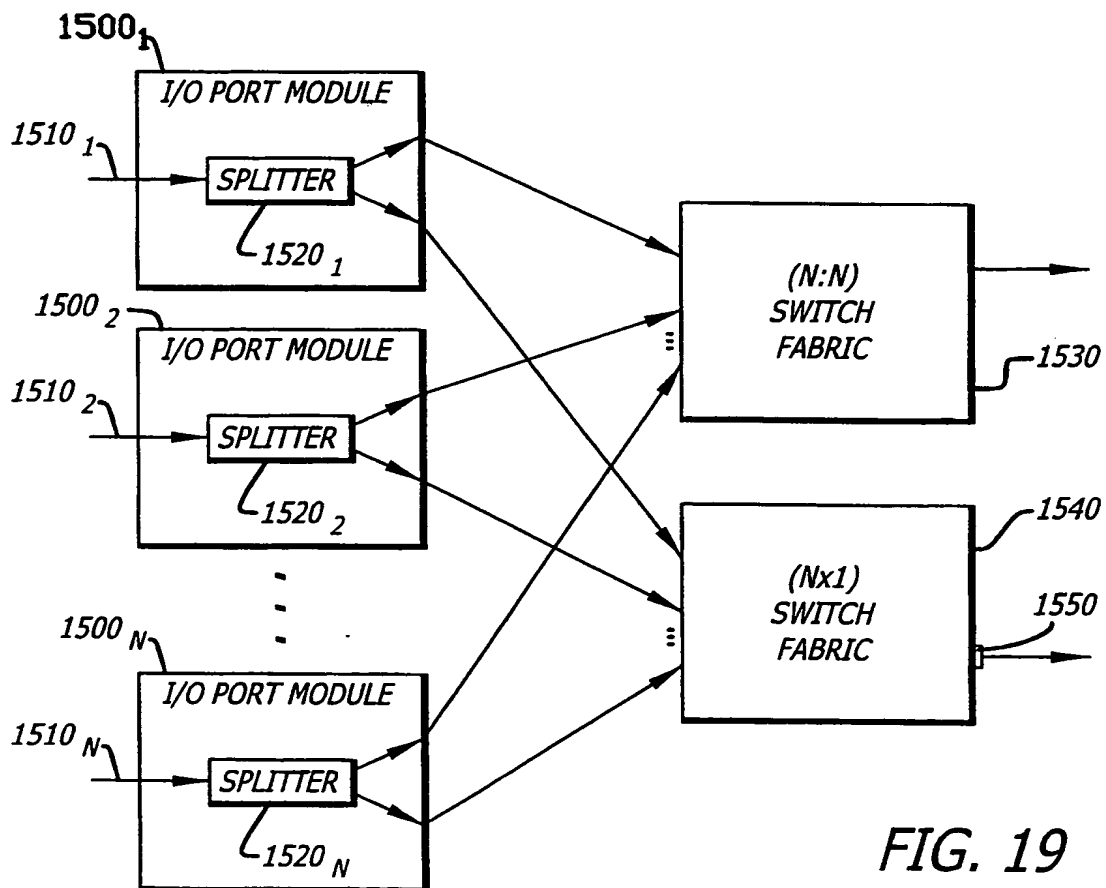


FIG. 19

FIG. 20a

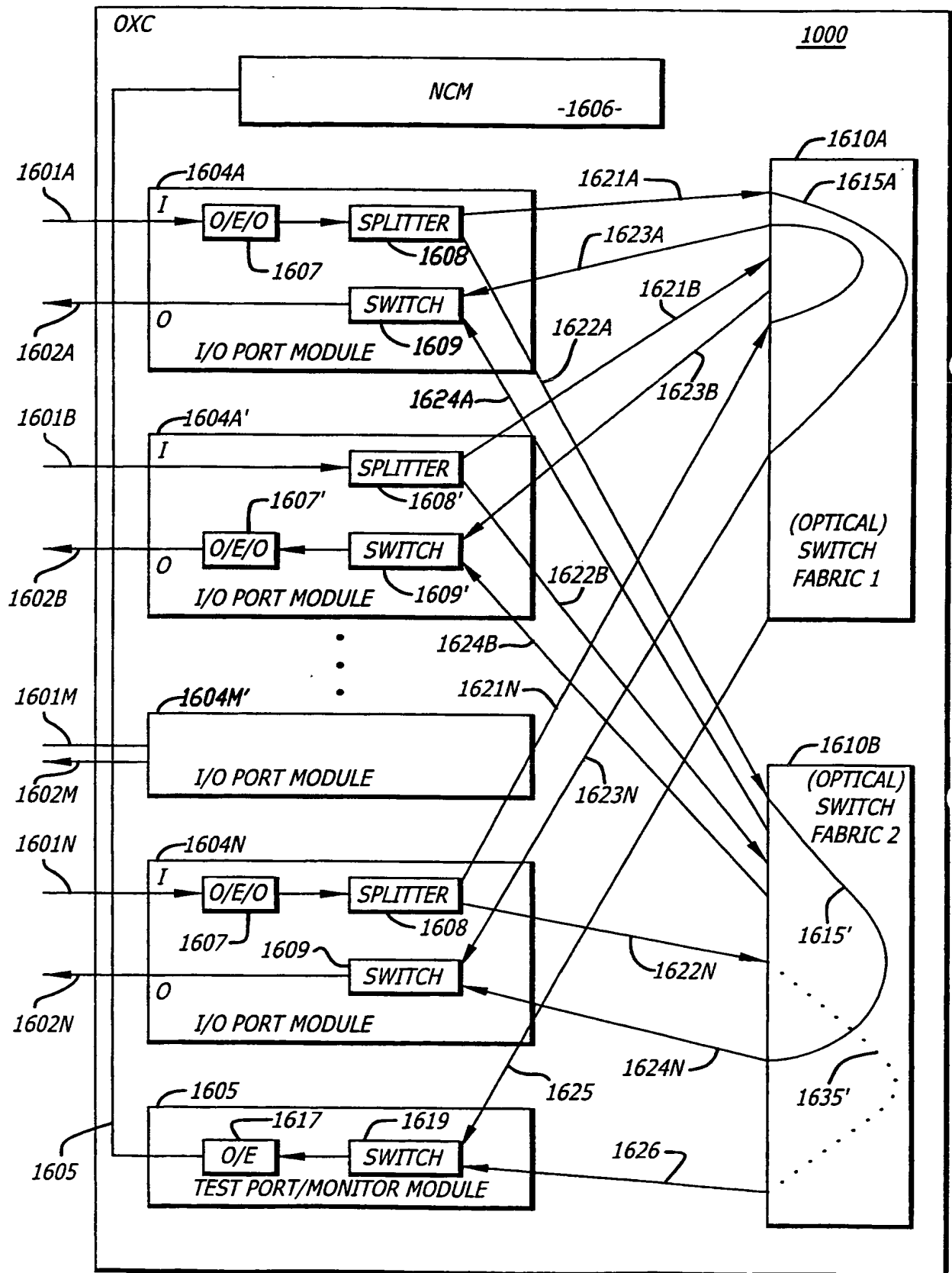


FIG. 20b

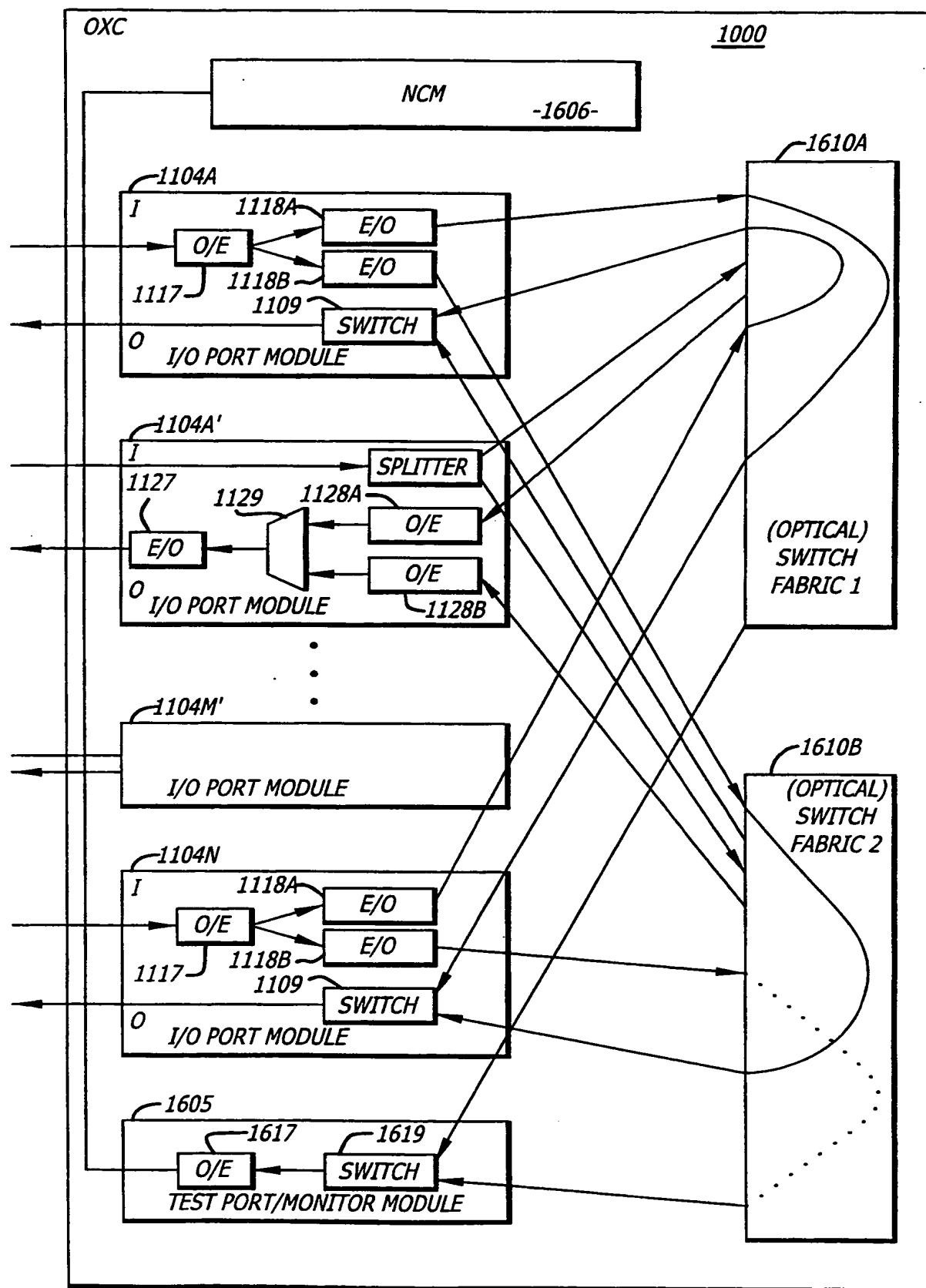


FIG. 20c

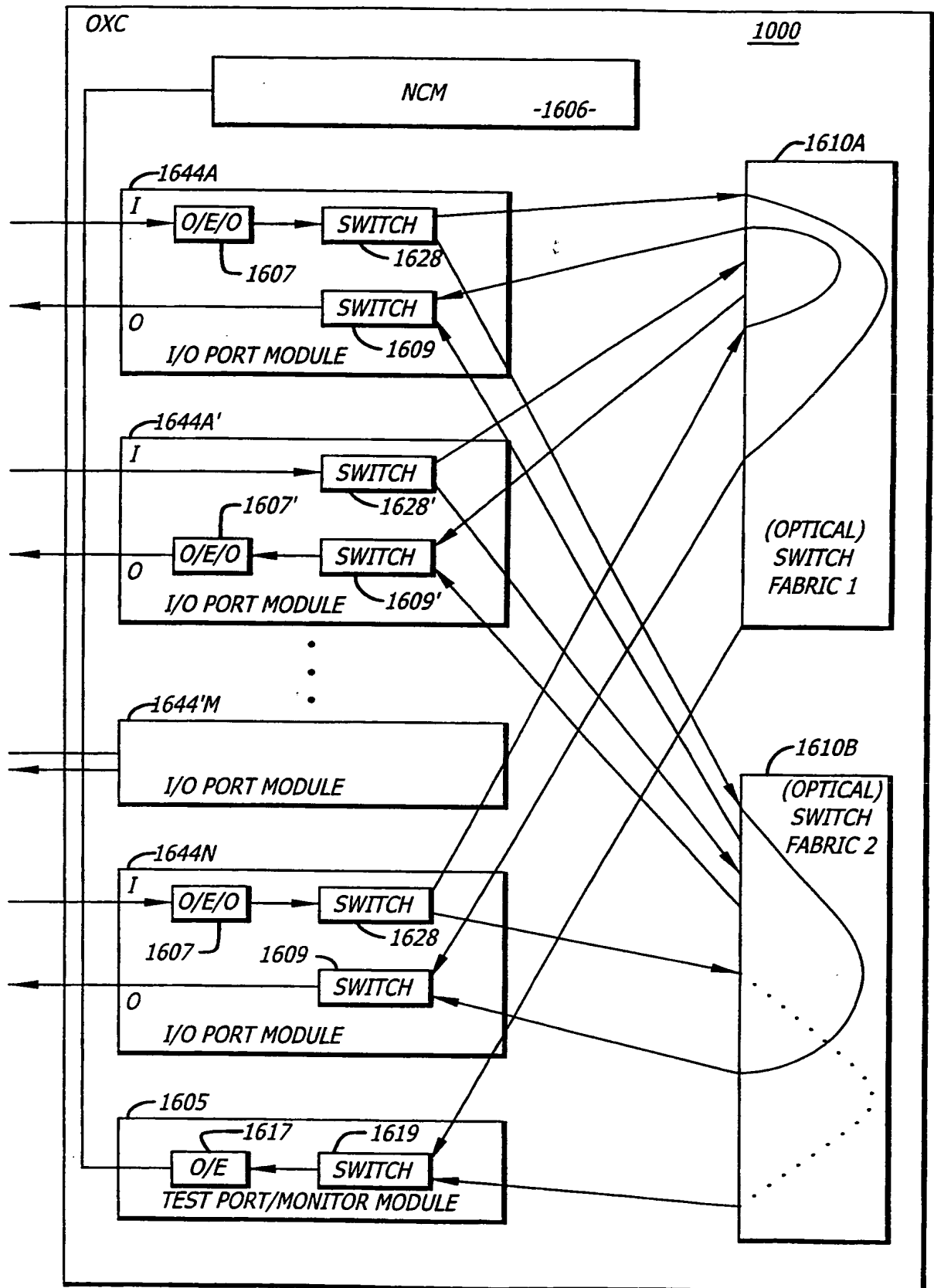


FIG. 20d

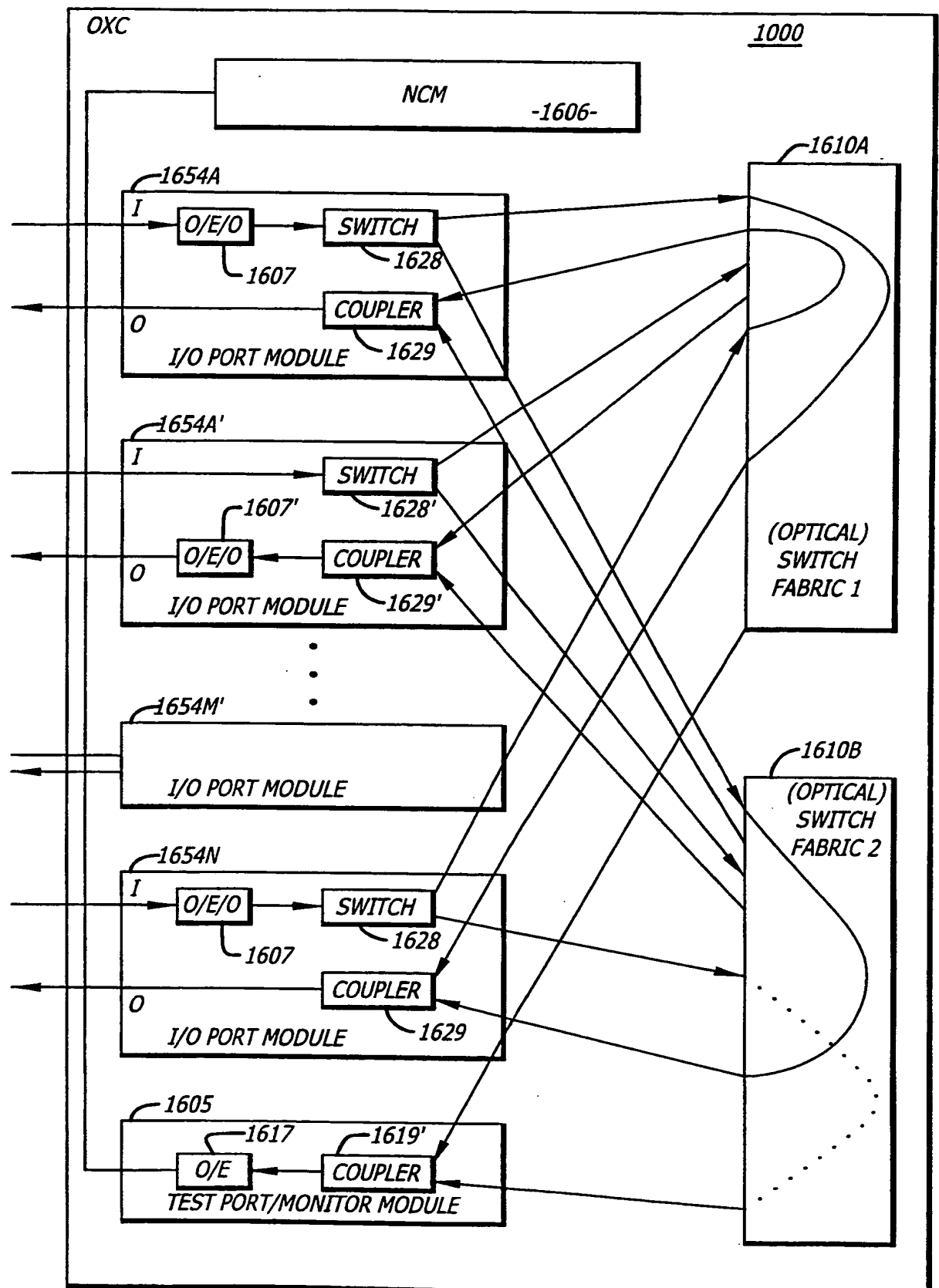


FIG. 20e

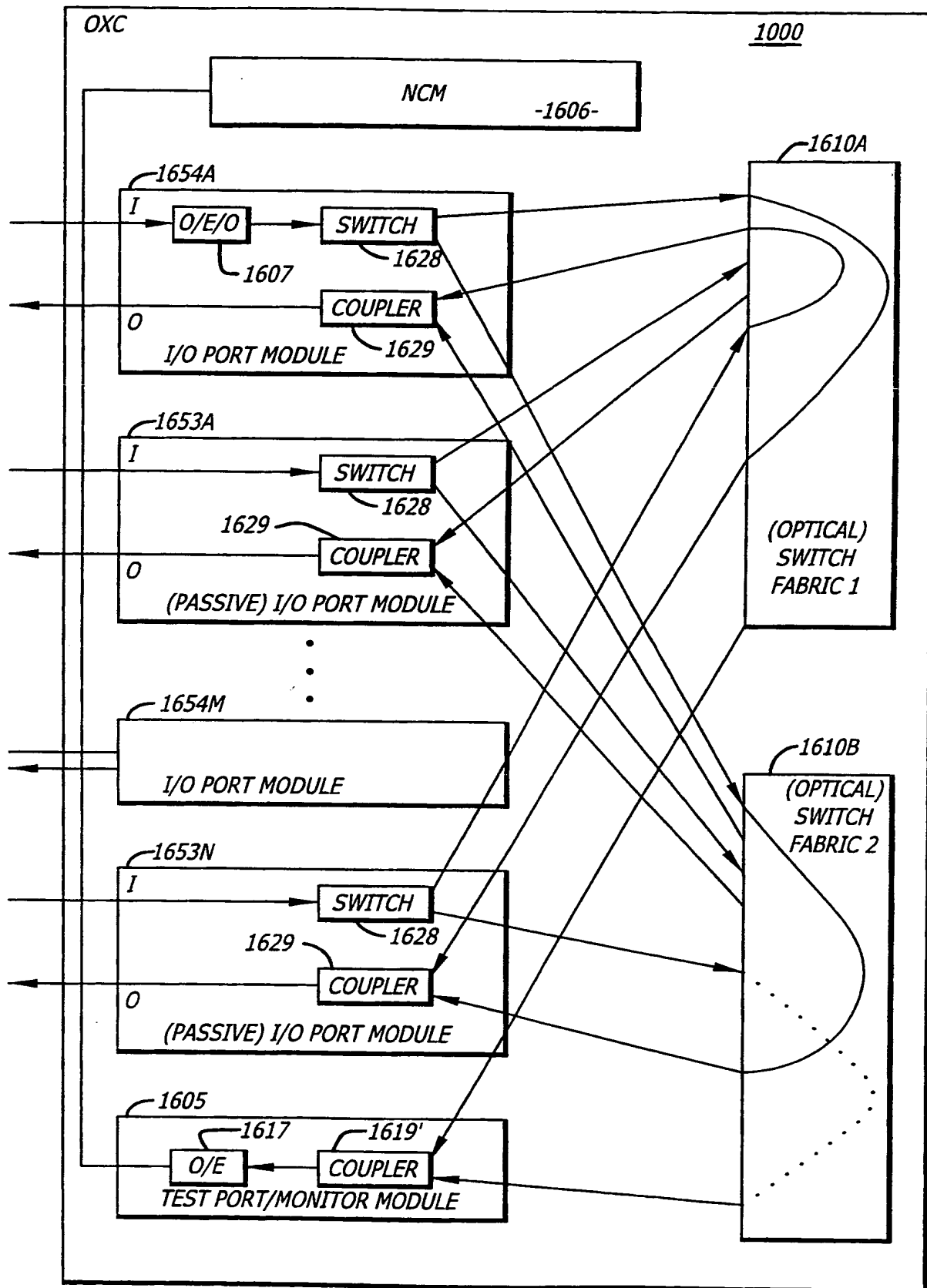




FIG. 20f

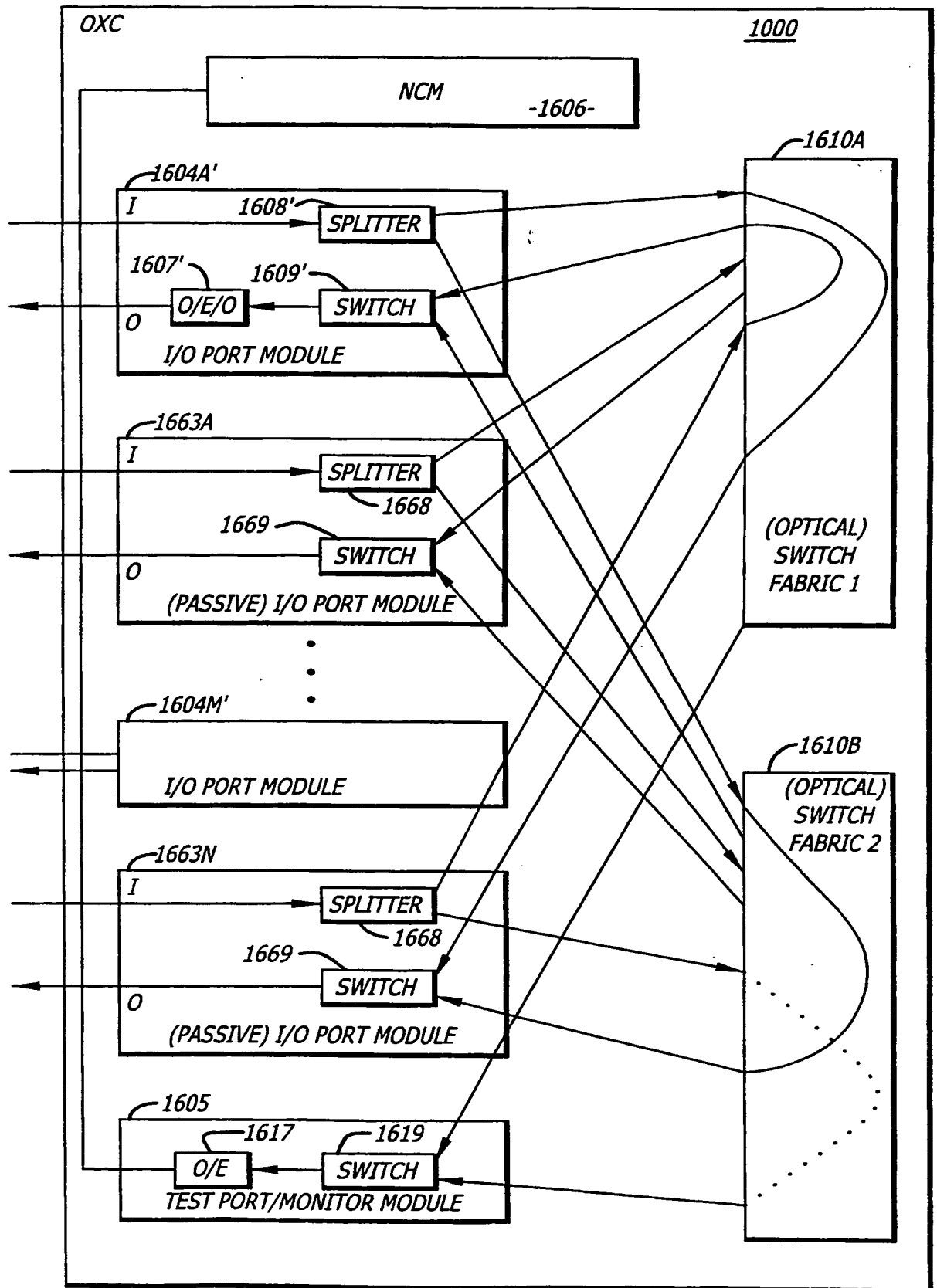


FIG. 21

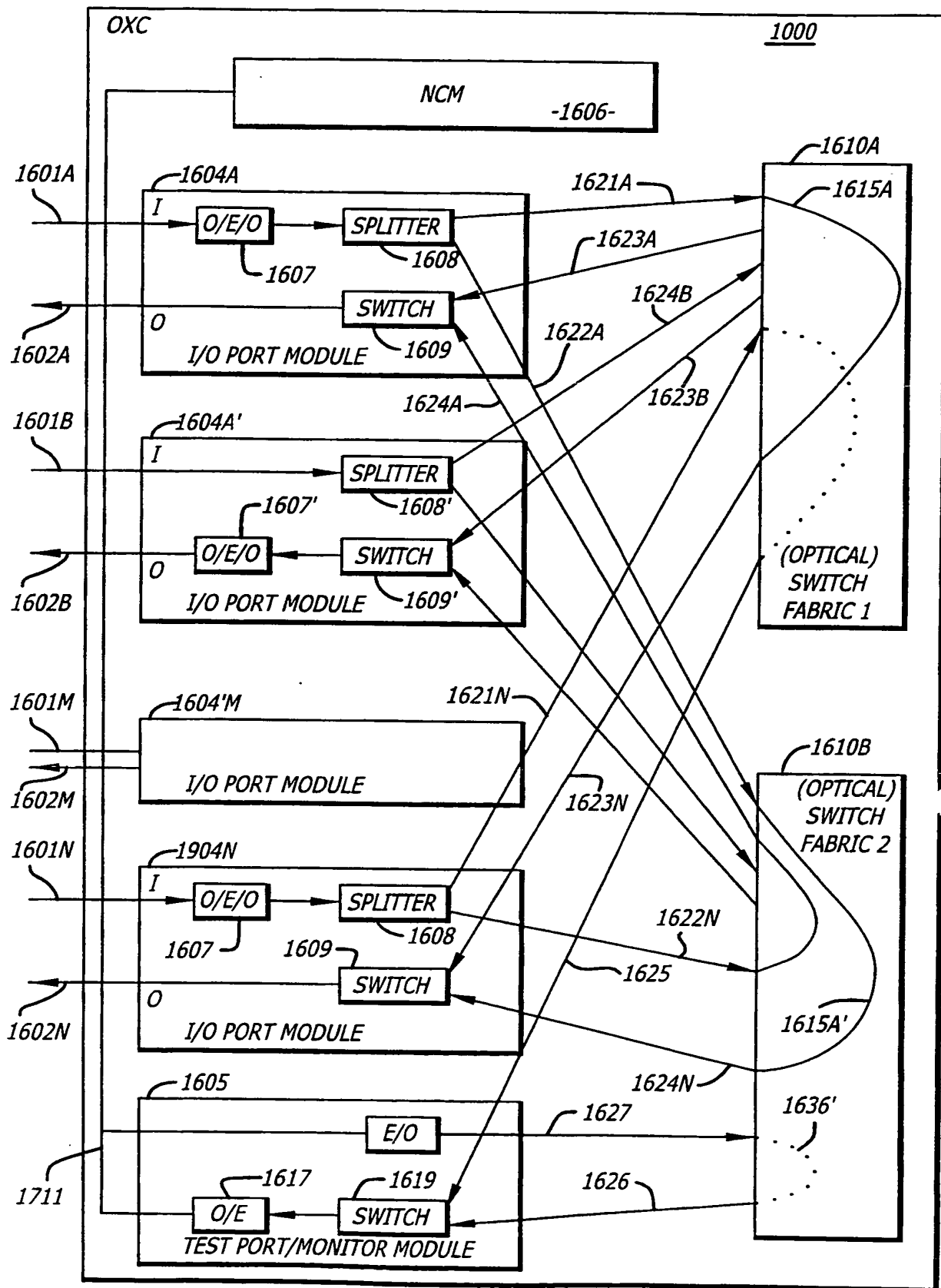
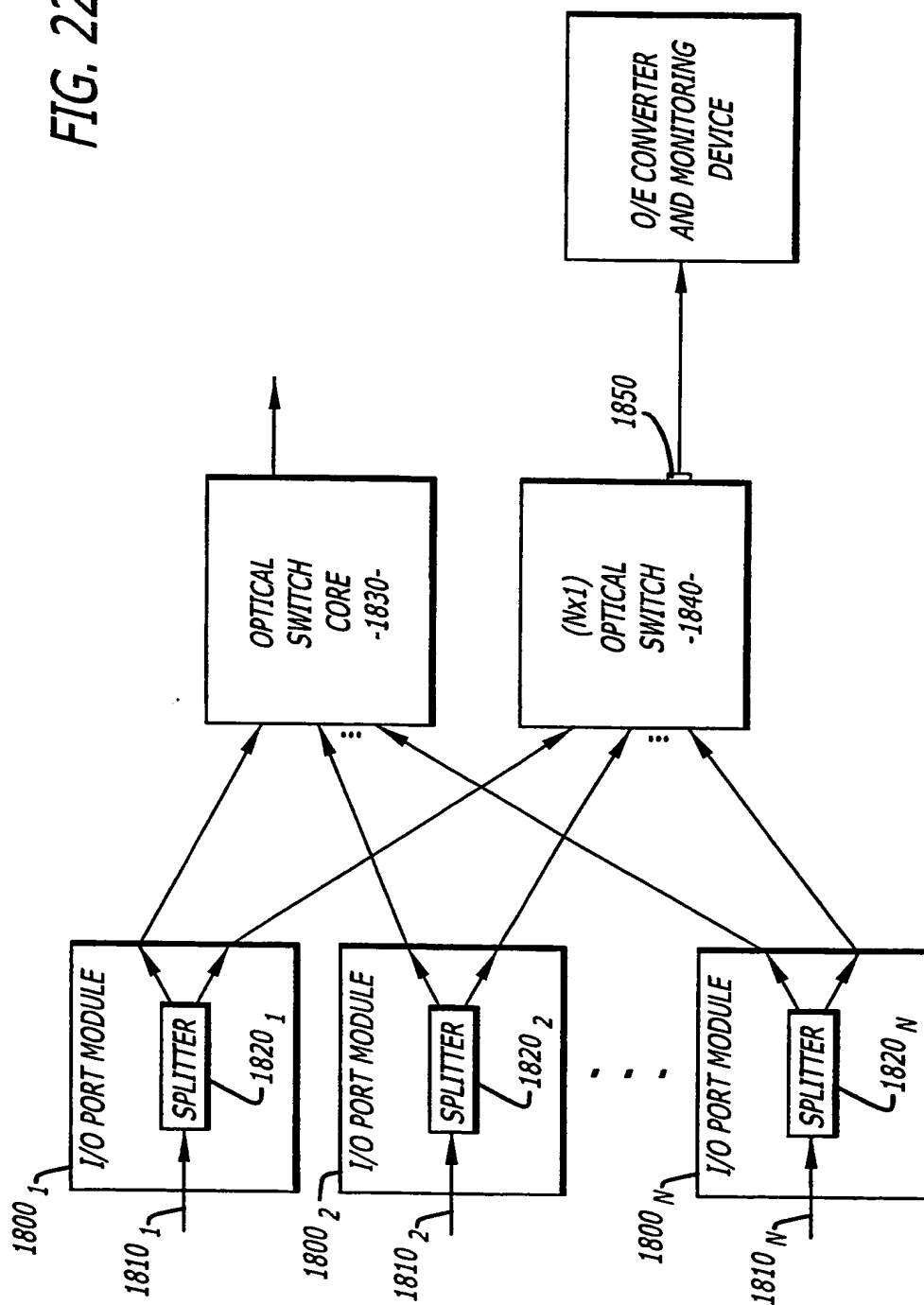


FIG. 22



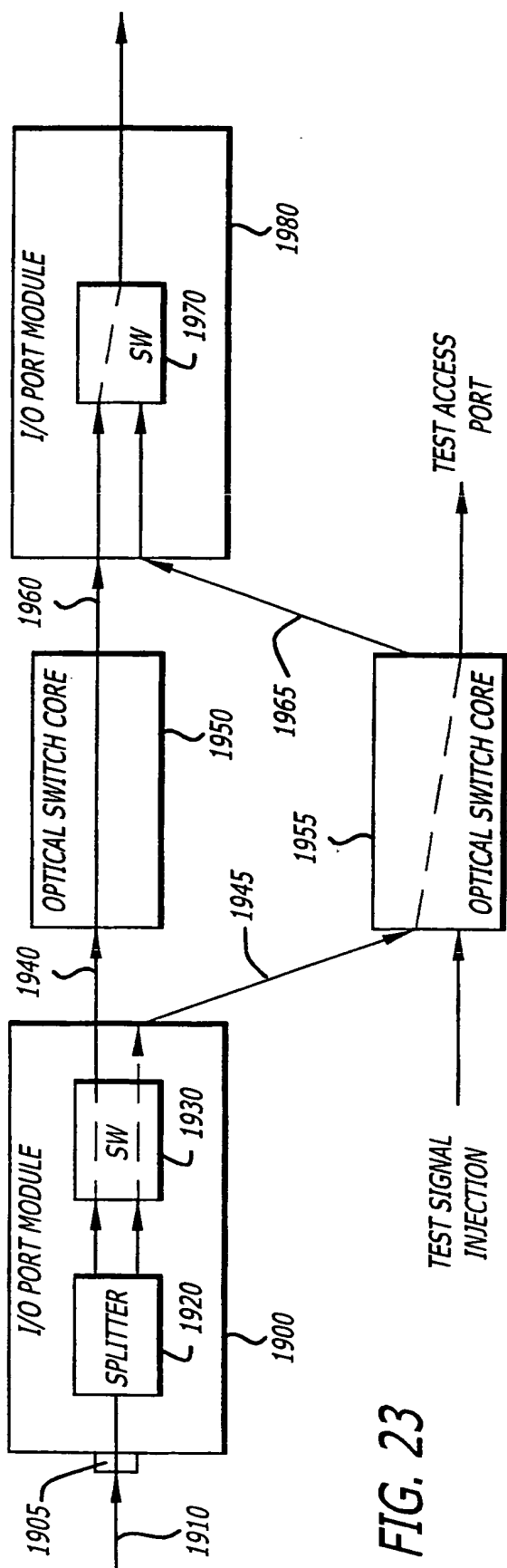


FIG. 23

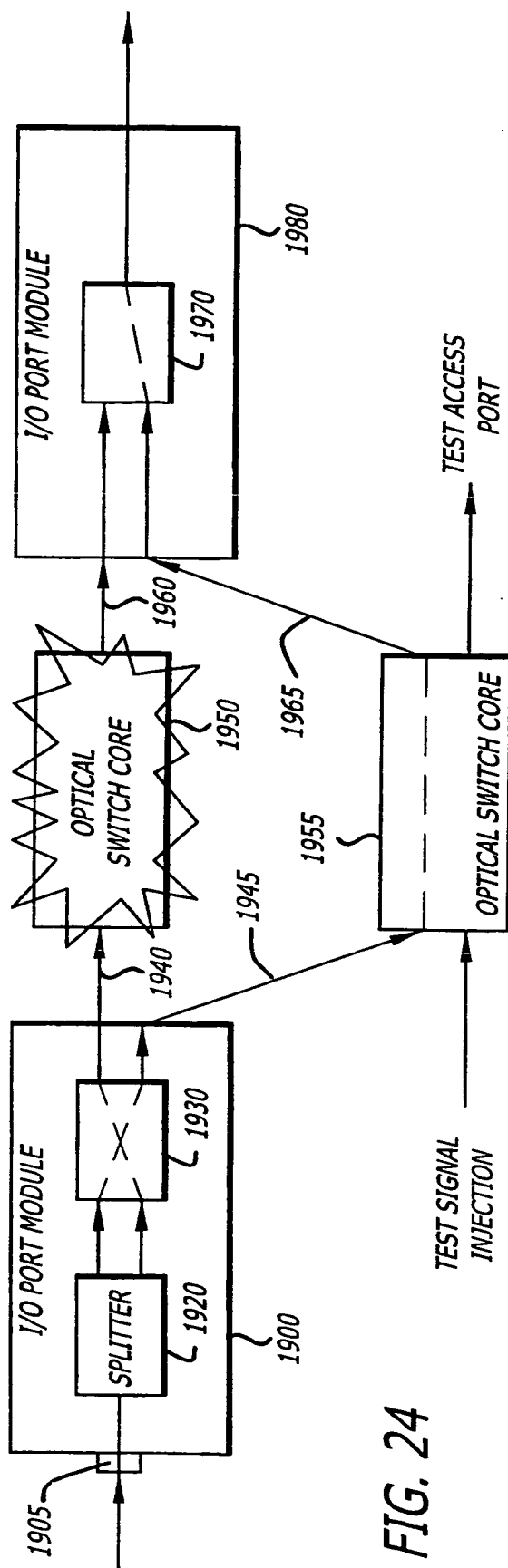


FIG. 24

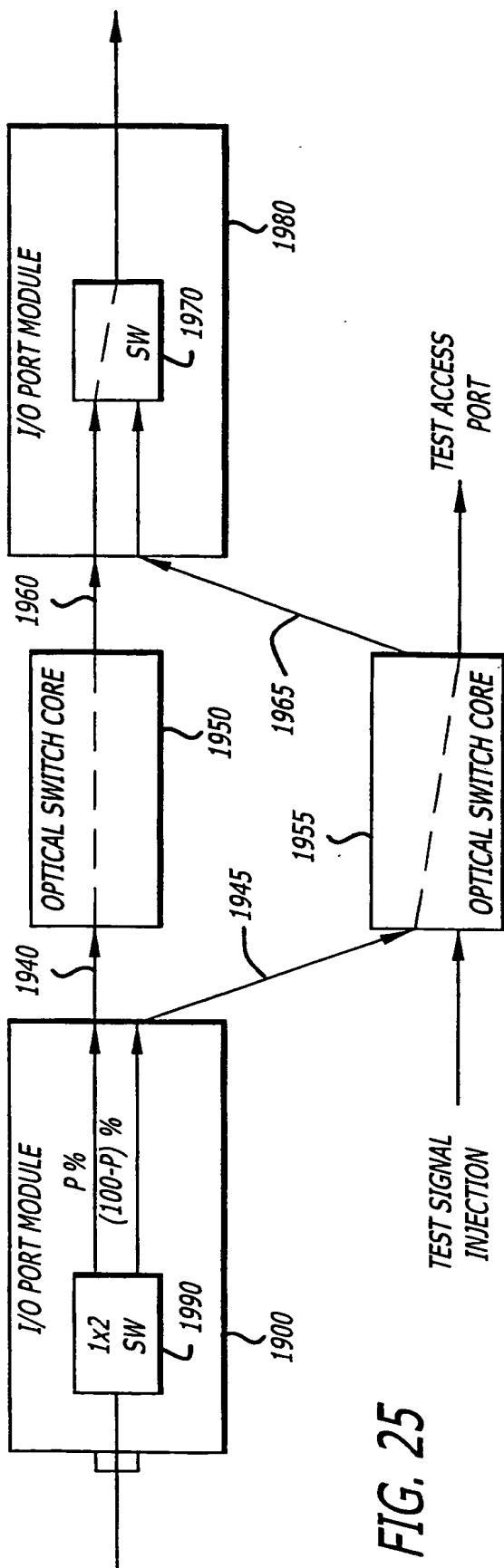


FIG. 25

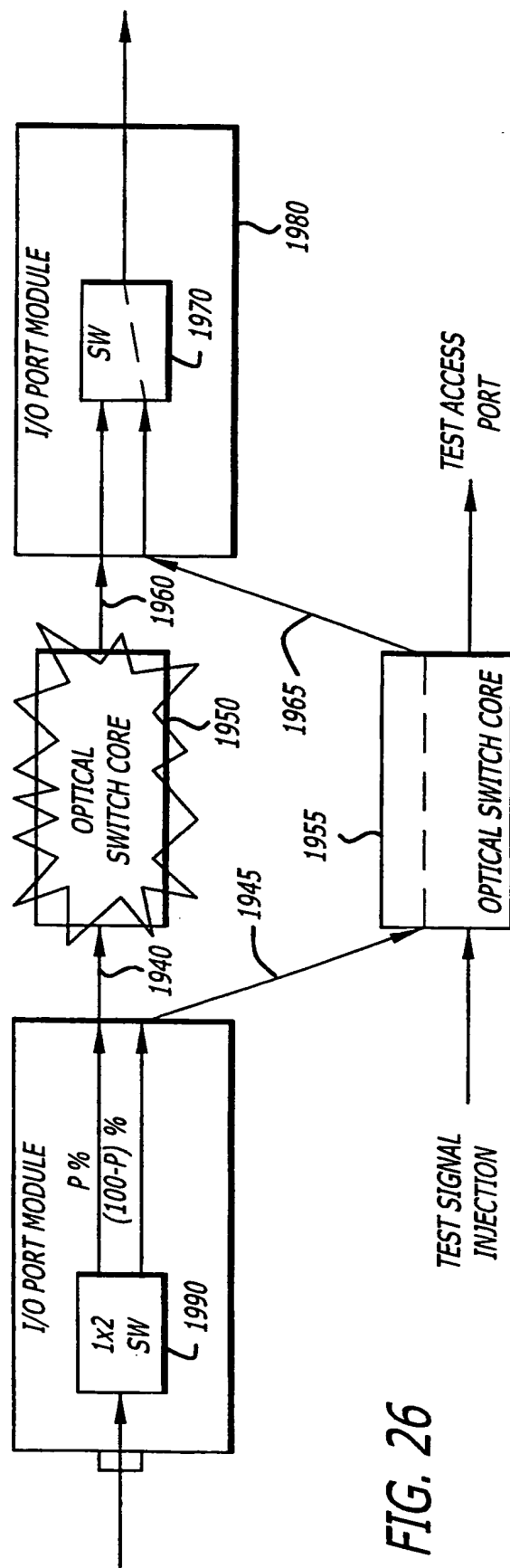
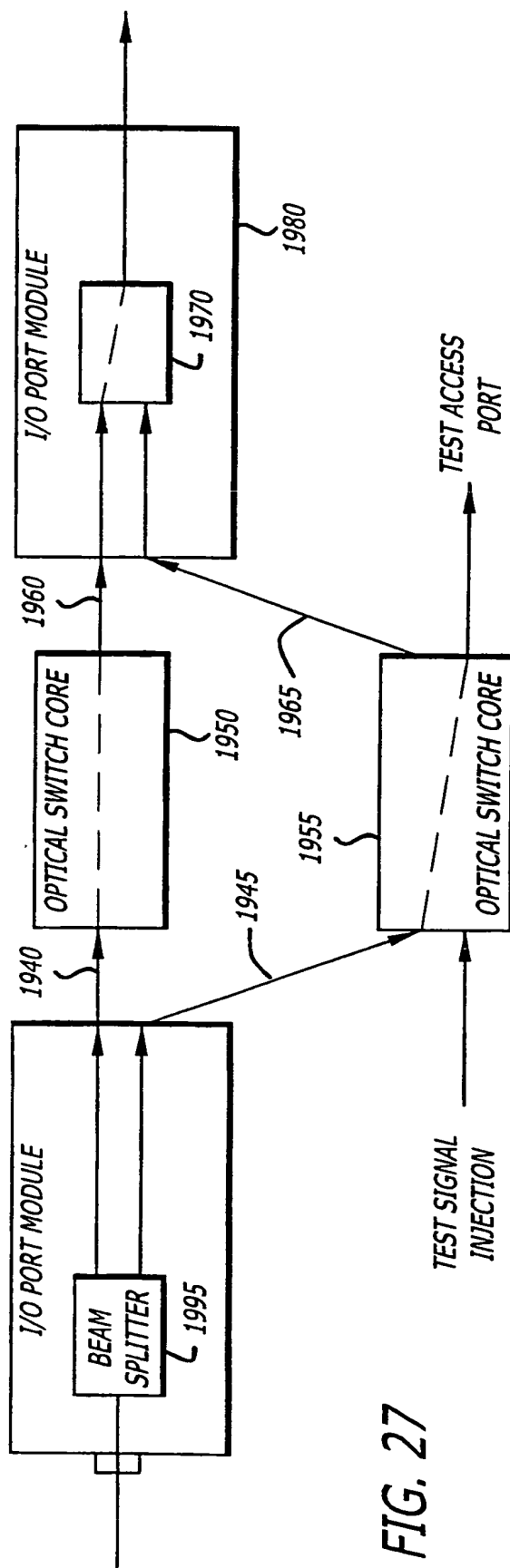


FIG. 26



# INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 00/30494

<b>A. CLASSIFICATION OF SUBJECT MATTER</b> IPC 7 H04Q11/00		
According to International Patent Classification (IPC) or to both national classification and IPC		
<b>B. FIELDS SEARCHED</b> Minimum documentation searched (classification system followed by classification symbols) IPC 7 H04Q		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practical, search terms used) EPO-Internal, WPI Data		
<b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>		
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 938 244 A (FUJITSU LTD) 25 August 1999 (1999-08-25)	7-9, 14, 15, 17-20, 22, 27, 29, 31, 32 1, 33
A	abstract paragraphs '0003!-'0012! figure 6A column 29, line 6-9	
A	WO 99 40738 A (TOL JOHANNES JACOBUS GERARDUS ;KONINKL KPN NV (NL)) 12 August 1999 (1999-08-12) abstract	4, 11, 33
A	EP 0 857 000 A (NIPPON ELECTRIC CO) 5 August 1998 (1998-08-05) abstract	1-38
-/-		
<input checked="" type="checkbox"/> Further documents are listed in the continuation of box C. <input checked="" type="checkbox"/> Patent family members are listed in annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier document but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art. "8" document member of the same patent family		
Date of the actual completion of the international search  3 August 2001		Date of mailing of the international search report  10/08/2001
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax (+31-70) 340-3016		Authorized officer  Dhondt, E

Form PCT/ISA/210 (second sheet) (July 1992)

# INTERNATIONAL SEARCH REPORT

In ternational Application No  
PCT/US 00/30494

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 849 906 A (FUJITSU LTD) 24 June 1998 (1998-06-24) column 61, line 56 -column 62, line 3 -----	7
A	EP 0 674 457 A (FUJITSU LTD) 27 September 1995 (1995-09-27) figures 48,49 -----	16,28,30



# INTERNATIONAL SEARCH REPORT

Information on patent family members

In. tional Application No

PCT/US 00/30494

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0938244 A	25-08-1999	JP 11239100 A	31-08-1999
WO 9940738 A	12-08-1999	NL 1008206 C	06-08-1999
		AU 2718299 A	23-08-1999
		EP 1053647 A	22-11-2000
EP 0857000 A	05-08-1998	JP 3006680 B	07-02-2000
		JP 10224828 A	21-08-1998
		US 6061156 A	09-05-2000
EP 0849906 A	24-06-1998	JP 10178418 A	30-06-1998
		CN 1185688 A	24-06-1998
		US 6178564 A	12-09-2000
EP 0674457 A	27-09-1995	JP 7307745 A	21-11-1995
		CA 2144837 A	18-09-1995
		US 5610913 A	11-03-1997

Form PCT/ISA/210 (patent family annex) (July 1992)